Acerca de este libro

Esta es una copia digital de un libro que, durante generaciones, se ha conservado en las estanterías de una biblioteca, hasta que Google ha decidido escanearlo como parte de un proyecto que pretende que sea posible descubrir en línea libros de todo el mundo.

Ha sobrevivido tantos años como para que los derechos de autor hayan expirado y el libro pase a ser de dominio público. El que un libro sea de dominio público significa que nunca ha estado protegido por derechos de autor, o bien que el período legal de estos derechos ya ha expirado. Es posible que una misma obra sea de dominio público en unos países y, sin embargo, no lo sea en otros. Los libros de dominio público son nuestras puertas hacia el pasado, suponen un patrimonio histórico, cultural y de conocimientos que, a menudo, resulta difícil de descubrir.

Todas las anotaciones, marcas y otras señales en los márgenes que estén presentes en el volumen original aparecerán también en este archivo como testimonio del largo viaje que el libro ha recorrido desde el editor hasta la biblioteca y, finalmente, hasta usted.

Normas de uso

Google se enorgullece de poder colaborar con distintas bibliotecas para digitalizar los materiales de dominio público a fin de hacerlos accesibles a todo el mundo. Los libros de dominio público son patrimonio de todos, nosotros somos sus humildes guardianes. No obstante, se trata de un trabajo caro. Por este motivo, y para poder ofrecer este recurso, hemos tomado medidas para evitar que se produzca un abuso por parte de terceros con fines comerciales, y hemos incluido restricciones técnicas sobre las solicitudes automatizadas.

Asimismo, le pedimos que:

+ *Haga un uso exclusivamente no comercial de estos archivos* Hemos diseñado la Búsqueda de libros de Google para el uso de particulares; como tal, le pedimos que utilice estos archivos con fines personales, y no comerciales.

+ *No envíe solicitudes automatizadas* Por favor, no envíe solicitudes automatizadas de ningún tipo al sistema de Google. Si está llevando a cabo una investigación sobre traducción automática, reconocimiento óptico de caracteres u otros campos para los que resulte útil disfrutar de acceso a una gran cantidad de texto, por favor, envíenos un mensaje. Fomentamos el uso de materiales de dominio público con estos propósitos y seguro que podremos ayudarle.

+ *Conserve la atribución* La filigrana de Google que verá en todos los archivos es fundamental para informar a los usuarios sobre este proyecto y ayudarles a encontrar materiales adicionales en la Búsqueda de libros de Google. Por favor, no la elimine.

+ *Manténgase siempre dentro de la legalidad* Sea cual sea el uso que haga de estos materiales, recuerde que es responsable de asegurarse de que todo lo que hace es legal. No dé por sentado que, por el hecho de que una obra se considere de dominio público para los usuarios de los Estados Unidos, lo será también para los usuarios de otros países. La legislación sobre derechos de autor varía de un país a otro, y no podemos facilitar información sobre si está permitido un uso específico de algún libro. Por favor, no suponga que la aparición de un libro en nuestro programa significa que se puede utilizar de igual manera en todo el mundo. La responsabilidad ante la infracción de los derechos de autor puede ser muy grave.

Acerca de la Búsqueda de libros de Google

El objetivo de Google consiste en organizar información procedente de todo el mundo y hacerla accesible y útil de forma universal. El programa de Búsqueda de libros de Google ayuda a los lectores a descubrir los libros de todo el mundo a la vez que ayuda a autores y editores a llegar a nuevas audiencias. Podrá realizar búsquedas en el texto completo de este libro en la web, en la página `http://books.google.com`

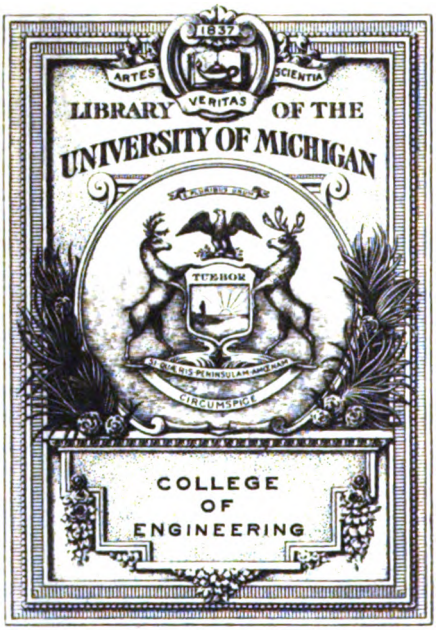
This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

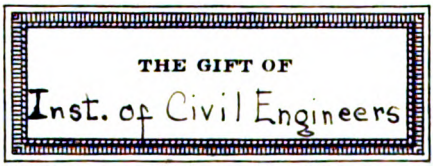
Google™ books

https://books.google.com

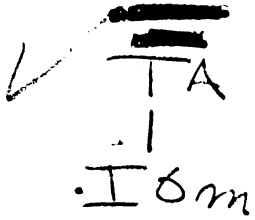
A 522503

Digitized by Google





Digitized by Google



Digitized by Google

Digitized by Google

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS.

VOL. 222.

EDITED BY

H. H. JEFFCOTT, SC.D., B.A.I., ASSOC. M. INST. C.E., SECRETARY.

LONDON:

Published by The Institution,

GREAT GEORGE STREET, WESTMINSTER, S.W. 1.

[TELEGRAMS, "INSTITUTION, LONDON." TELEPHONE, "VICTORIA, 4577."]

1926.

[*The right of Publication and of Translation is reserved.*]

Digitized by Google

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made or for the opinions expressed in the following pages.

NOTICE.

To ensure the punctual delivery of the Minutes of Proceedings, and of other communications from The Institution, it is essential that every change of address should be notified without delay to—

THE SECRETARY,

THE INSTITUTION OF CIVIL ENGINEERS,

Great George Street, Westminster, S.W. 1.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
DUKE STREET, STAMFORD STREET, S.E. 1, AND GREAT WINDMILL STREET, W. 1

Digitized by Google

Institution
gift
5-18-1927

CONTENTS.

MINUTES OF PROCEEDINGS.

23 *February*, 1926.

PAGE

"The Khyber Railway." V. BAYLEY. (1 plate and 3 cuts) . . 1
"The Survey and Construction of the Khyber Railway." Colonel Sir GORDON HEARN. (2 cuts) 23
Discussion on the two foregoing Papers 47
Correspondence on ditto. (1 cut) 54

9 *March*, 1926.

Associate Members transferred to the class of Members 79
Admission of Students 79
Election of Associate Members and an Associate 79
"The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile." O. L. PROWDE. (1 plate and 1 cut) 81
Discussion on ditto 100
Correspondence on ditto 113

23 *March*, 1926.

Announcement of the deaths of Sir Bradford Leslie, Sir Philip Watts, and Professor W. H. Warren, former Members of Council . . 121
"The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland." A. E. TUFFLEY. (8 cuts) 121
Discussion on ditto 142
Correspondence on ditto (1 cut) 148

13 *April*, 1926.

Associate Members transferred to the class of Members 157
Admission of Students 157
Election of Members, Associate Members and Associates 157
"The Influence of Electric Welding in the Design and Fabrication of Plant and Structures." J. N. REESON. (1 plate and 4 cuts) . 158
Discussion on ditto 181
Correspondence on ditto. (3 cuts) 188

Digitized by Google

27 *April*, 1926.

PAGE

Associate Members transferred to the class of Members 211
Admission of Students 211
Election of Members, Associate Members and an Associate . . . 211
"The Triple-Expansion Steam-Engine as applied to the Pumping of Water, with special reference to the Plant at Lea Bridge." H. R. LUPTON. (1 plate) 212
Discussion on ditto. (1 cut) 238
Correspondence on ditto 250

11 *May*, 1926.

Annual General Meeting 267
Election of the Council for 1926–27 267
Report of the Council: Session 1925–26 269
Appendix—Balance Sheet and Accounts 287
Original Communications received, 1925–26 300

EXTRA MEETING.

26 *October*, 1926.

"Radio Communications." Senator G. MARCONI. (The Thirty-second James Forrest Lecture.) (3 cuts) 303

Obituary 321
INDEX 324

PLATES.

PLATE 1 illustrating Mr. V. BAYLEY's Paper, "The Khyber Railway."
„ 2 „ Mr. O. L. PROWDE's Paper, "The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile."
„ 3 „ Mr. J. W. REESON's Paper, "The Influence of Electric Welding in the Design and Fabrication of Plant and Structures."
„ 4 „ Mr. H. R. LUPTON's Paper, "The Triple-Expansion Steam-Engine as applied to the Pumping of Water."

Digitized by Google

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1925-1926.—PART 2.

MINUTES OF PROCEEDINGS.

23 February, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D.Eng., in the Chair.

The following Papers were presented for discussion, and on the motion of the President, the thanks of The Institution were accorded to the Authors.

(*Paper No. 4588.*)

"The Khyber Railway."

By VICTOR BAYLEY, C.I.E., M. Inst. C.E.

THE Khyber Pass, which lies in the north-west corner of India, is one of the most important routes between India and the rest of Asia. At all times a trade route for caravans, it has also been the line of advance of numerous invasions of India. The Pass lies outside British India, and the surrounding inhospitable mountains are the home of savage and warlike tribes. Their land is variously described as "tribal territory," "unadministered territory," or more definitely "the Khyber Agency," and is under the care of the Political Agent of the Khyber. It is in truth a "no man's land," where there is no law but tribal custom, and where human life and property are lightly esteemed. The construction of an engineering work of some magnitude in such country presented peculiar problems, which could often only be solved by unconventional methods.

General Description.—The railway (Figs. 1, 2, and 3, Plate 1, and *Fig. 4*) is a single line of 5-foot 6-inch gauge, and is $27\frac{3}{4}$ miles long from Jamrud to the Afghan frontier. The maximum gradient from Jamrud to the summit at Landi Kotal is 3 per cent., and from Landi Kotal down to the frontier 4 per cent. The thirty-four tunnels have an aggregate length of 3 miles. The quantity of earthwork in banks and cuttings is 3 million cubic yards. There are ninety-two

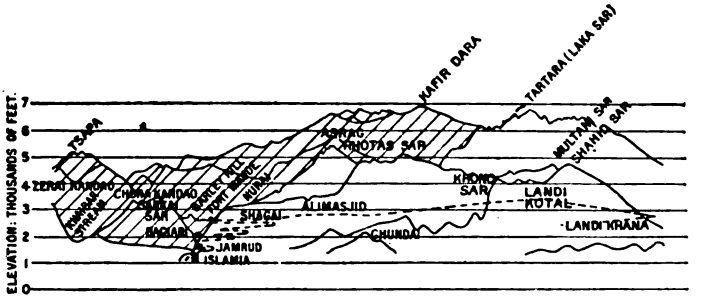
Digitized by Google

bridges and culverts, but none of great size. The railway, which contains four combined crossing- and reversing-stations and six crossing-stations, rises from 1,496 feet above sea-level at Jamrud to 3,494 feet above sea-level at Landi Kotal in a distance of 21 miles, and descends to 2,622 feet above sea-level at Landi Khana in a further distance of 4½ miles. The frontier lies 2 miles beyond Landi Khana, down a gradient of 4 per cent. The railway is built to the new (1923) recommended dimensions providing for an overall loading-gauge 12 feet wide and 15 feet 6 inches high.

Location (Figs. 2 to 8, Plate 1).

Jamrud to Shahgai.—The jaws of the subsidiary pass, which is followed by the roads and defended by posts, lie about 3 miles west of Jamrud fort, and the stream-bed there is at an elevation of about 1,800 feet. On either side of the jaws are considerable masses, to the north joining on to the main range by a continually rising spur, and to the south joined by a spur to the Shahgai heights,

Fig. 4.



The Railway passes between Plain and Hatched Ranges

Diagrammatic Elevation of Railway.

which have a level of about 2,700 feet. Just west of Fort Maude is a spur, the lowest saddle in which is at a height of about 2,650 feet, rising again to Barley Hill and then trending westward to the mass of Sarkai, with the lowest saddle at an elevation of 2,300 feet on the watershed of the Khyber nullah. Since the "air line" distance from the jaws to the Barley Hill ridge west of Fort Maude is only 2 miles, and since the rise is 750 feet, the railway crosses the basin and doubles back by means of two reversing-stations, in order to limit the gradient to 3 per cent. These reversing-stations can be taken out by substituting spiral loops at considerable expense when traffic renders this financially advisable.

Digitized by Google

Shahgai to Kata Kushta.—The line beyond Shahgai has been taken through to the Ali Masjid gorge as low as possible, and it follows the south or right bank of the stream as far as is practicable, although this involved heavy tunnelling. Since 1898 much work has been done on the roads in the gorge, and a ropeway which ran through the gorge during the construction of the railway would have caused mutual interference with a low-level railway. Apart from this, however, it was considered that a high-level line through the gorge would provide the most favourable alignment; and it was decided to rise as rapidly as possible from Shahgai and to take the line through the gorge 100 feet or more above the road. The easing of the gradient brings the alignment down to valley-level near the village of Kata Kushta, about 2 miles above Ali Masjid, where the gorge may be considered to end.

Kata Kushta to Landi Kotal.—This portion of the route lies in the upper Khyber valley, which gradually widens out. At first the side slopes are steep down to the stream, which flows in a rather wide bed, winding from side to side of the valley; but after a few miles the stream remains confined to a deeper bed, and there are terraced slopes on each side. At Zintara a sharp spur juts out from the south right up to the stream, which here has a very sharp double bend, but immediately above there is a considerable widening out of the main valley, under the influence of two subsidiary valleys. The steady rise of about 1 in 50 made it difficult to locate the stations, but suitable sites have been found at Zintara and Sultan Khel. At Landi Kotal summit there is a considerable outcrop of rock, dividing the saddle into two portions. The cantonment lies to the north of this outcrop, and the station has been placed to the south, as giving the best alignment for approaching the difficulties of the descent to the Afghan border.

Landi Kotal to Landi Khana.—The drainage from the west side of Landi Kotal flows to Landi Khana down a single valley, the hills to the north and south rising to considerable heights. This valley starts comparatively gently, but there is a waterfall about ¾ mile from Landi Kotal. In the next 3,000 feet the stream falls about 250 feet, and then comes another waterfall, after which again there is a moderate fall until, opposite Michni fort, the bed falls 500 feet in ¾ mile to Landi Khana. It was decided to leave the main valley as soon as possible, to enter the Tora Tigga valley by tunnelling through the intervening spurs, and to reverse, bringing the line back down the left bank of the Tora Tigga, and by a short tunnel into Landi Khana. Here another reverse gives a straight

Digitized by Google

lead towards Dakka, and, after a short distance, the work becomes much easier. It will be possible in the future to obviate reversing-stations by tunnelling at the turn of the Tora Tigga and following the right bank.

The Tribes.

The tribes chiefly concerned are Afridis, Shinwaris, and to a less extent Shilmanis and Mullagoris. The Afridis inhabit the lower and easternmost spurs of the Sufed Koh range to the west and south-west of the Peshawar district, including the valleys of Maidan and of the Bara streams. They are divided into sections, each holding territory of its own, and each section is again sub-divided into innumerable khels, families, and parties, fiercely jealous of each other and often openly at blood feud. The Shinwaris, who inhabit the neighbourhood of Landi Kotal and Landi Khana, are a fragment of a numerous and powerful clan, the bulk of which resides in Ningrahar on the northern slopes of the Sufed Koh as subjects of the Amir of Afghanistan. They maintain a tradition of friendship with the British Government. Like the Afridis they also are seamed with enmity and feuds. Much has been written about the characteristics of these lawless and independent clansmen. While their habit of murdering anyone standing in their way, and the terrible history of their blood feuds, invite condemnation, yet their virility, humour, intelligence, and sturdy independence of character exert an irresistible charm. It was natural that misgiving was felt at the outset as to the attitude the tribesmen would adopt towards the proposed invasion of their territory by a railway. The Political Agent expressed confidence that with tact and care they could be led into accepting the railway, and stressed the importance of understanding and maintaining friendly relations with them. The necessity of obtaining the whole-hearted co-operation of the tribesmen in the construction of the railway was deemed to be of paramount importance, and an enhancement of rates to a point somewhat above the economic limit was suggested as a powerful inducement. The wisdom of these views was fully borne out by experience, though it was not found necessary to offer unduly enhanced rates. The unit cost of earthwork was the same on the Khyber Railway as it had been 15 years previously on the Loi Shilman Railway, and the cost of the tunnels per foot compares favourably with the Loi Shilman costs. In the period intervening between the construction of the two railways, the cost of labour had risen enormously —for example, a khassadar on the Loi Shilman Railway cost Rs. 11 per month, compared with Rs. 30 on the Khyber Railway. The

Digitized by Google

economy secured on the Khyber Railway works was therefore remarkable, and it was due to a significant extent to the friendly feeling between the railway officers and the tribes. Work was delayed for a long time for political reasons over a length of 8 miles from Kata Kushta to a point near Landi Kotal. Lengthy negotiations went on between the Political Agent and the tribe concerned, and it was not until the beginning of 1922 that the Political Agent permitted work to start. Meanwhile amicable relations had been established, and once work was started it was possible to push on rapidly and make up for lost time. The Author lived for 4 years at Landi Kotal, among the tribesmen in their own country, and looks back to many happy hours spent in their company.

Tribal Labour and Contractors.—It was considered to be of vital necessity to interest the tribes in the railway by allotting work to them, and seeing that they made on the whole a reasonably good profit. The employment of tribal labour on daily rates of pay was an obvious and simple method of ensuring these two objects, but there were grave objections to this course. The general rise in prices and wages during the great war had affected the north-west, and an added impetus had been given to the rise by the third Afghan war, the rate of pay in the Khyber having risen to R. 1 a day per man. Not only was the prospect of paying this rate disquieting, but it was also known that neither Afridis nor Shinwaris were enamoured of hard work, and that hours of labour would be short, owing to the danger of moving about except during broad daylight. It was decided, therefore, that piece-work should be used wherever possible for all works, and a system of allotting petty contracts at definite rates was devised. There was nothing new in this, as it had been customary for military works in the Khyber to be carried out on this system; but the magnitude of the work was entirely unprecedented in the district. The Political Agent exercises a measure of control over the tribes in his Agency in various ways outside the scope of this Paper. He is able to exert his authority and to bring pressure to bear on the tribesmen, both collectively and individually, often by using the time-honoured influence of the tribal *jirga* (assembly). He possesses an intimate knowledge of tribal customs, and is fully informed regarding the intricacies of tribal politics. It was therefore ruled that the Political Agent alone should select the individuals to work petty contracts. These "contractors" were, of course, entirely ignorant of railway construction. The system evolved was for the executive engineer of a division to apply to the Political Agent for a contractor for a specific work. The Political Agent then nominated a man and

Digitized by Google

sent him to the executive engineer, who entered into a formal agreement with the contractor regarding the rates at which the work was to be done, and set the contractor to work. In order to guide the Political Agent in the selection of contractors from among men of greatly varying influence in the tribes, contracts were classified A, B, C, etc., according to their estimated value to the contractors. The next point for settlement with the tribes was the proposed importation of labour. In regard to unskilled coolie labour, not much difficulty was anticipated. There was a seasonal influx of coolies from Ningrahar, Mohmand country, and Kashmir, especially during the winter. The tribesmen dealt with these men in their own fashion and stubbornly opposed any importation of coolies by the railway. Time proved that the coolie labour position was not too bad; labour was never plentiful, but was sufficient to complete the railway within the estimated period. As regards skilled labour, the tribes were, on the whole, reasonable. They recognized that they had no skill in masonry, carpentry, blacksmith work, etc., and they offered no opposition to the establishment of construction workshops with imported workmen. In the case of brick and stone masonry in bridges and tunnels, they at first desired to undertake the work on contract rates while employing masons themselves. Most of them found, however, that their technical ignorance landed them in constant troubles with their masons, and consequently masonry was carried out departmentally. These arrangements were only arrived at after months of negotiations. The situation confronting the engineers at the outset was that the Khyber Railway had to be undertaken through the agency and in the territory of savage tribes, regarded with terror by the skilled workmen it was desired to import, fiercely jealous of their traditional rights, and to some extent hostile to the whole project. At the end of 1920 the difficulties ahead appeared very menacing, and opinions were freely expressed that the construction of the Khyber Railway was impossible, or at any rate only possible at a prohibitive cost; but when harmonious relations with the tribes had been established, difficulties began to disappear, and eventually all were overcome.

Security.—During the early stages of the enterprise the country was unsettled after the Afghan war, outrages and murders on the road were not infrequent, and generally a feeling of insecurity was abroad. There were, however, certain camps and posts occupied by military forces at Jamrud, Shahgai, Ali Masjid, Landi Kotal, and Landi Khana, and these became the headquarters of divisions and sub-divisions. Quarters were built inside the barbed-wire

Digitized by Google

perimeters at these places for officers, subordinates, works establishment, and imported skilled labour. All concerned had to be inside the perimeter during the hours of darkness, with a substantial margin of daylight at evening and in the morning. The staff was distributed in the morning and collected in the evening by motor-lorry, and this ensured their security while at their quarters: there remained the larger matter of security on works. Considerable freedom of movement was necessary, as the inconvenience of having an armed escort with every officer, subordinate, or mistry would have been intolerable. The Political Agent therefore devised an arrangement, which worked extremely well. A large force of railway khassadars, numbering at one period 570, was recruited by the Political Agent and undertook to protect the railway works from raids. The principle of tribal responsibility is well established in the Khyber. Under conditions arrived at in *jirga*, the tribes will accept responsibility for a certain arrangement, and will honourably carry out their undertaking. In case of failure they will then pay a penalty without argument, and it is to their interest to see that no failure occurs. Such an arrangement was the enlistment of railway khassadars. The men were drawn from all sections of the tribes, and not only picketed heights and kept a look-out for raiders, but also watched each other. It was thus impossible for any untoward incident to occur without the circumstances being fully known and reported to the Political Agent, who could then take action and fix responsibility. This irregular force completely fulfilled its purpose. Raids and thefts naturally occurred, but they were well under control, and often stolen property was recovered. The protection of unskilled labour was dealt with in a slightly different manner. It was impossible, for obvious reasons, to house tribal labour inside perimeter camps, which were cleared of tribesmen at sunset. It was necessary, however, to provide some form of housing, as most of the Khyber Railway passes through uninhabited country. Thirteen labour camps were therefore built, and they were defended by khassadar posts on the neighbouring heights. These camps were provided with piped water, sanitary staff, and shopkeepers, and became so well established that it was even possible in some cases to house imported labour there. It is an indication of the common sense of the tribesmen where a common advantage is to be gained that the camps were completely peaceful although containing a mixture of races and tribes. No control could be exercised directly, as, of course, no railway officers or subordinates could be present at night. Although individual escorts were

Digitized by Google

not normally provided, there were unusually insecure places, such as the Tora Tigga valley, where escorts were desirable. Occasionally, too, the Political Agent would notify the presence of a raiding gang, and on such occasions khassadar escorts were necessary until the coast was clear. Khassadar protection cost Rs. 8,75,000, and this sum has been distributed over the works as an addition to their cost.

Housing, Sanitation, and Welfare.—Owing to the hardships of life in the Khyber, the health and contentment of the construction staff were of primary importance. The climate is healthy, but hurricanes are liable to sweep the Pass at all times of the year, and are particularly trying in winter. The range of temperature between summer maximum and winter minimum is about 100° F. The housing of the staff had, therefore, to be done on rather a better scale than is usual on construction. At the same time accommodation was very limited inside perimeter camps, and quarters had to be of small dimensions. Electric light and fans were installed at Jamrud, Shahgai, Ali Masjid, and Landi Kotal. A generous allowance of fuel was given during the winter months. Medical attention was organized by the civil surgeon, Peshawar, who received an allowance as medical officer of the Khyber Railway. Sanitary staff was attached to each camp under a sub-assistant surgeon, and hospital accommodation was provided at Jamrud and Landi Kotal. Cooks were allowed to superior staff and to gangs of workmen. In order to provide recreation and amusement a sum of money was sanctioned for starting institutes at Jamrud, Shahgai, and Landi Kotal.

Plan of Operations.

The barren character of the Khyber was the dominant feature determining the plan of operations, and it was evident that heavy importation of fuel, cement, bricks, lime, sand, etc., would be necessary, as well as of the usual construction plant and stores. The situation was slightly eased by the discovery of brick clay at Landi Kotal, but all coal had to be carried from railhead at Jamrud 20 miles away and 2,000 feet below. The costliness of works would therefore increase with their distance from railhead. At the same time, in view of the heaviness of the work, construction by pushing rail-head out and carrying out works as rail-head approached was impracticable. It was therefore decided to advance rail-head as soon as possible over easy country to Bagiari, to press on with all works up to Landi Kotal, to start all earthwork and

Digitized by Google

minor works beyond Landi Kotal, and, finally, to commence all other works beyond Landi Kotal, but not to proceed too rapidly with them until the arrival of rail-head at Landi Kotal. This plan was modified by the discovery that Michni tunnel, 1½ mile beyond Landi Kotal, would involve unusual engineering difficulties. It was therefore decided to press on with all works up to and including that tunnel. Nature assisted this plan, for beyond Michni tunnel there is little bridging, and the remaining tunnels were found to be to some extent in such hard shale that they could be opened out wide enough to squeeze a ballast-train through, leaving the necessary roof-lining and final widening to be done with materials railed up by ballast-train.

Materials.—The Khyber is situated far from manufacturing centres, from which it would have been impossible to import materials except at a prohibitive cost. It is customary on Indian engineering works to "live on the country" as far as possible. Importation of permanent-way material, Portland cement, timber, and fuel, was, however, unavoidable. At an early stage the search for quarries, brick clay, water, and raw materials for lime making was prosecuted vigorously.

Water.—Water flows out from springs in large quantities at Ali Masjid and Landi Khana. The military authorities had carried out an extensive pumping-scheme between Shabgai and Landi Kotal. This water-supply system was invaluable and was extended by the railway to supply nearly all works. Between Landi Kotal and Landi Khana, however, a number of small springs were tapped by the railway, from which an independent supply was obtained.

Building Stone.—The railway runs through limestone for many miles, and it was hoped that good building-stone would be obtained either from cuttings or from quarries. The limestone, however, was found to be irregular and badly fissured. Near Landi Kotal some fairly good quarries were opened, and the stone was used for neighbouring works. On the whole, however, the use of local building-stone had to be abandoned.

Lime.—The Khyber limestone was burnt in continuous kilns with slack coal, and gave a quicklime which slaked vigorously to form a fat lime. This was unsuitable for building important works, but when the lime was mixed with 1 to 1½ part of surkhi (finely-powdered brick-dust) the resulting mixture formed an excellent building mortar with marked hydraulic properties.

Bricks.—Brick-clay was found near Jamrud and also at Landi Kotal. Bull kilns were installed at both places and were worked by tribal contractors. Coal for brick-burning at Landi Kotal was

Digitized by Google

conveyed from Jamrud by Sentinel steam-wagons. The cost of first-class bricks at Jamrud was Rs. 25, and at Landi Kotal Rs. 45 per thousand. Surkhi was made at the brick-kilns by grinding brick-bats in disintegrators driven by portable steam-engines.

Concrete.—For works near rail-head at Jamrud broken limestone was used with sand imported by rail, but the cost of transporting sand for more than a mile or so was prohibitive. Fortunately the bed of the Khyber nullah contained gravel which made an excellent 4-to-1 Portland cement concrete. This was largely used for bridge works and tunnel-linings, as well as for many small reinforced-concrete articles.

Mortar.—Lime mortar consisted of 1 part slaked lime to 1 or 1½ part surkhi; the different mixtures represented the individual tastes of the engineers concerned, and there seemed to be no difference between them. One part of Portland cement was mixed with 2 parts of sand for important works, and with 3 parts of sand for other works. Between Landi Kotal and Landi Khana sand was unobtainable, and the cost of importing it was prohibitive; hence, when Portland-cement mortar had to be used, the unusual expedient was adopted of mixing 1 part of cement with 2 parts of surkhi. Tests showed that this mortar was equivalent in strength to a mortar containing 1 part of cement to 3 of sand. Cement was supplied by the Punjab Portland Cement Company.

Construction.

Earthwork.—Earthwork was started at Landi Kotal in December, 1920, in Shinwari territory, in order to test the attitude of the tribes towards railway construction and to gain experience as to rates. A few contractors were nominated by the Political Agent, and negotiations commenced. It must not be imagined that a brief discussion took place at once, and that the matter was then settled. The reader must rather picture a word spoken when opportunity permitted. Eventually the contractors agreed to start work and see what happened. The upshot was that tribesmen earning R. 1 per day of 6 hours did on an average 50 cubic feet of earthwork per man per day, corresponding to a rate of Rs. 20 per 1,000 cubic feet, without profit to the contractor. This was rather alarming, but facts had to be faced, and after endless bargaining an initial rate of Rs. 20 per 1,000 cubic feet was agreed upon. Similar considerations led to the following schedule of rates for earthwork and rock-cutting of all sorts—

Digitized by Google

minor works beyond Landi Kotal, and, finally, to commence all other works beyond Landi Kotal, but not to proceed too rapidly with them until the arrival of rail-head at Landi Kotal. This plan was modified by the discovery that Michni tunnel, 1½ mile beyond Landi Kotal, would involve unusual engineering difficulties. It was therefore decided to press on with all works up to and including that tunnel. Nature assisted this plan, for beyond Michni tunnel there is little bridging, and the remaining tunnels were found to be to some extent in such hard shale that they could be opened out wide enough to squeeze a ballast-train through, leaving the necessary roof-lining and final widening to be done with materials railed up by ballast-train.

Materials.—The Khyber is situated far from manufacturing centres, from which it would have been impossible to import materials except at a prohibitive cost. It is customary on Indian engineering works to "live on the country" as far as possible. Importation of permanent-way material, Portland cement, timber, and fuel, was, however, unavoidable. At an early stage the search for quarries, brick clay, water, and raw materials for lime making was prosecuted vigorously.

Water.—Water flows out from springs in large quantities at Ali Masjid and Landi Khana. The military authorities had carried out an extensive pumping-scheme between Shahgai and Landi Kotal. This water-supply system was invaluable and was extended by the railway to supply nearly all works. Between Landi Kotal and Landi Khana, however, a number of small springs were tapped by the railway, from which an independent supply was obtained.

Building Stone.—The railway runs through limestone for many miles, and it was hoped that good building-stone would be obtained either from cuttings or from quarries. The limestone, however, was found to be irregular and badly fissured. Near Landi Kotal some fairly good quarries were opened, and the stone was used for neighbouring works. On the whole, however, the use of local building-stone had to be abandoned.

Lime.—The Khyber limestone was burnt in continuous kilns with slack coal, and gave a quicklime which slaked vigorously to form a fat lime. This was unsuitable for building important works, but when the lime was mixed with 1 to 1½ part of surkhi (finely-powdered brick-dust) the resulting mixture formed an excellent building mortar with marked hydraulic properties.

Bricks.—Brick-clay was found near Jamrud and also at Landi Kotal. Bull kilns were installed at both places and were worked by tribal contractors. Coal for brick-burning at Landi Kotal was

Digitized by Google

conveyed from Jamrud by Sentinel steam-wagons. The cost of first-class bricks at Jamrud was Rs. 25, and at Landi Kotal Rs. 45 per thousand. Surkhi was made at the brick-kilns by grinding brick-bats in disintegrators driven by portable steam-engines.

Concrete.—For works near rail-head at Jamrud broken limestone was used with sand imported by rail, but the cost of transporting sand for more than a mile or so was prohibitive. Fortunately the bed of the Khyber nullah contained gravel which made an excellent 4-to-1 Portland cement concrete. This was largely used for bridge works and tunnel-linings, as well as for many small reinforced-concrete articles.

Mortar.—Lime mortar consisted of 1 part slaked lime to 1 or 1½ part surkhi; the different mixtures represented the individual tastes of the engineers concerned, and there seemed to be no difference between them. One part of Portland cement was mixed with 2 parts of sand for important works, and with 3 parts of sand for other works. Between Landi Kotal and Landi Khana sand was unobtainable, and the cost of importing it was prohibitive; hence, when Portland-cement mortar had to be used, the unusual expedient was adopted of mixing 1 part of cement with 2 parts of surkhi. Tests showed that this mortar was equivalent in strength to a mortar containing 1 part of cement to 3 of sand. Cement was supplied by the Punjab Portland Cement Company.

Construction.

Earthwork.—Earthwork was started at Landi Kotal in December, 1920, in Shinwari territory, in order to test the attitude of the tribes towards railway construction and to gain experience as to rates. A few contractors were nominated by the Political Agent, and negotiations commenced. It must not be imagined that a brief discussion took place at once, and that the matter was then settled. The reader must rather picture a word spoken when opportunity permitted. Eventually the contractors agreed to start work and see what happened. The upshot was that tribesmen earning R. 1 per day of 6 hours did on an average 50 cubic feet of earthwork per man per day, corresponding to a rate of Rs. 20 per 1,000 cubic feet, without profit to the contractor. This was rather alarming, but facts had to be faced, and after endless bargaining an initial rate of Rs. 20 per 1,000 cubic feet was agreed upon. Similar considerations led to the following schedule of rates for earthwork and rock-cutting of all sorts—

Digitized by Google

Earthwork	Rs.	20	per 1,000 cubic feet.
Soft shale	„	30	„ „
Medium shale	„	50	„ „
Hard „	„	70	„ „
Very hard „	„	100	„ „
Limestone	„	120	„ „

Including lift in all cases.
Blasting required and explosives to be provided by the Railway.

A few intermediate rates were applied in special cases. The amount of 50 cubic feet per man per day did not vary much, and these rates were adhered to throughout the work and gave satisfaction. The bulk of the work was in shale or limestone. Lead was paid for separately, but it was impracticable to assess lift correctly on the rough hillsides. The explosives used on earthwork were locally-manufactured gunpowder and imported gelignite. All cuttings required the use of explosives, and in some cases banks had to be built from borrow-pits worked with explosives. The quantity of explosives per 1,000 cubic feet was extraordinarily variable, and no useful figures can be given. Sometimes a large charge would be ineffective, and at other times a small charge would bring down a hillside. A figure of 3 lbs. of gunpowder per 1,000 cubic feet is, perhaps, an average. In working shale cuttings the best contractors would sink a narrow well about 2 feet 6 inches in diameter and 20 feet deep, 15 to 20 feet back from the working-face. In this a charge of 100 to 200 lbs. of gunpowder would be placed and well tamped. The resulting explosion showed very little effect on the surface, but shattered a large volume of shale which could then easily be removed by crowbar and shovel. The average cost of earthwork of all sorts was approximately Rs. 58 per 1,000 cubic feet. To this must be added special overhead charges, which are very heavy on the Khyber Railway, the principal items being the cost of khassadars for protection, sanitation, and distribution of staff by motor-lorries. These overhead charges raise the total average cost to Rs. 70 per 1,000 cubic feet.

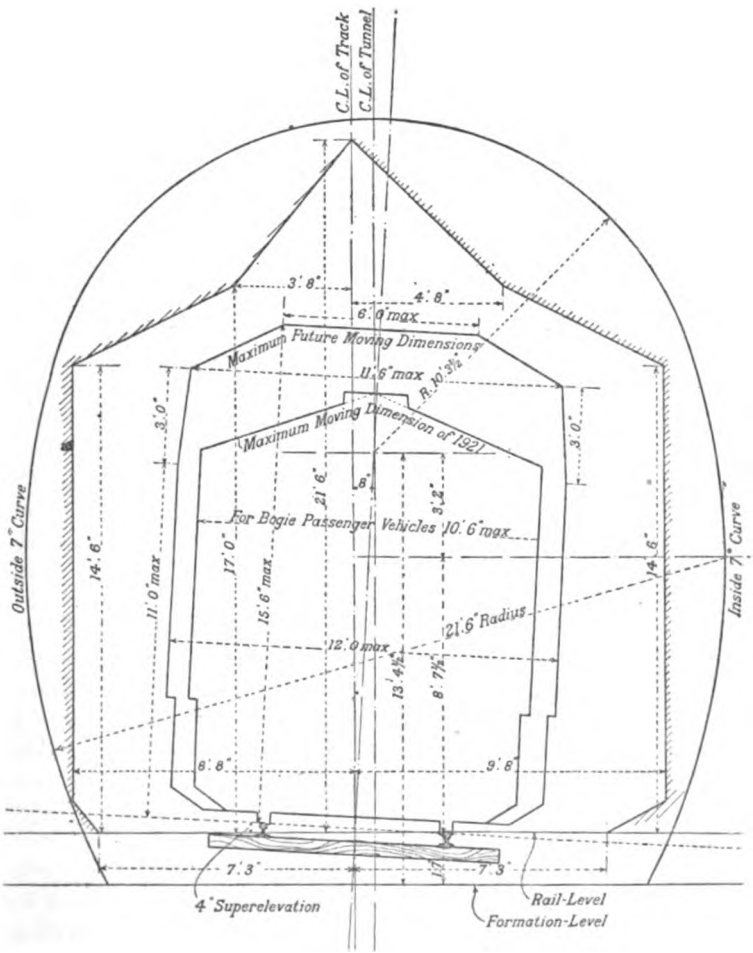
This account of negotiations with the tribesmen is typical, and the same introduction to starting all other works must be imagined. In the Khyber there was no possibility of calling for tenders or inviting competition. The first contractors to start incurred a good deal of unpopularity, and had occasionally to fight to retain their work. A few were murdered, and the first year or so of work was not without peculiar interest to the engineers, apart from the normal round of their duties.

Tunnels.—The longest tunnel is 520 yards long. All tunnels are for single line, and all curves in tunnels are of 7 degrees curvature.

Digitized by Google

Separate profile sections were therefore adopted for tunnels on a curve and those on a straight (*Fig. 9*, and Figs. 10, Plate 1). The Indian 5-foot 6-inch gauge standard dimensions for the loading-gauge on a 7-degree curve call for an addition to the loading-gauge for a

Fig. 9.



TUNNEL SECTION ON 7-DEGREE CURVE.

straight of 24 inches (later revised to 20 inches) on the inside of the curve and 8 inches on the outside. This was provided for by designing a suitable symmetrical section and then shifting it 8 inches towards the inside of the curve. A few other profiles with

Digitized by Google

flat, or nearly flat, sides were tried, but were found to be unable to resist pressure.

The roof portions of all tunnels were lined, except in one tunnel through very hard limestone. The sides were left unlined in limestone and in hard shale. In the latter case considerable care had to be exercised in deciding which portions of shale tunnels might be left with unlined sides. Shale is notoriously unreliable and liable to weathering, and it may be that in years to come all the shale tunnels will gradually be lined throughout. In shale of doubtful quality the tunnels are fully lined, and in one case, where the shale is very wet and unstable, a complete lining with invert for a length of 800 feet has been adopted. The material for lining was usually brick, owing to the ease and rapidity with which a brick arch can be built to support the roof. In limestone, however, where there was no urgency for the lining to keep pace with excavation, concrete was used.

In every case a heading was driven from both ends, and, if possible, from intermediate adits, before opening-out to full size commenced. This was done in order to verify the centre-line, which had in most cases been carried over rough and ravine-intersected country, and in order to explore the strata. Nearly all the tunnels were spirals with a steep gradient and sharp curvature. Bottom or top headings 7 feet by 7 feet were used, according to the individual preference of the engineer: probably a bottom heading is better in most cases. In hard shale or limestone no difficulty was experienced, and it was only necessary to break down the rock and enlarge the heading to the desired section by repeated drilling and blasting. In soft shale needing the use of timber great caution was necessary. The roof portion was excavated first, and, if a bottom heading was used, the spoil was disposed of down a small shaft into the heading. The roof was supported by the usual crown bars and cross timbers, which were pulled forward as excavation advanced. In bad ground the length of advance was usually 8 feet at a time, but this was reduced in very bad ground, sometimes to as short an advance as 3 feet.

Special Difficulties in Tunnels.—Unfortunately most of the Khyber Railway tunnels were in shale, and many of them were wet. Nearly all shale tunnels were liable to give trouble near their portals. The Khyber shale usually lies with both dip and strike tilted at a steep angle, and there are numerous faults, with the result that pockets of shale of rhomboidal shape become detached and fall out unexpectedly from an apparently solid mass. The shale in the side of a cutting will stand at a fairly steep average slope of

Digitized by Google

about ½ to 1, but it is constantly liable to discharge irregular masses from its face. Warning was generally given by the occurrence of cracks on the surface of the ground adjacent to the cutting. Similarly, on the commencement of a tunnel in the face of a shale hill, the opening of fissures in the hillside above the tunnel began to occur. The significance of these was not grasped at first, and it was thought that, as soon as tunnel-lining was firmly established under the cracked face of the hill, the strata would settle down and remain stable. The true state of affairs, however, was that the hill was preparing to discharge a detached rhomboidal mass from its face. This tendency increased with the passage of time, and it was enhanced by the infiltration of water into the fissures and by the shaking of the hill by blasting-operations in the tunnel below. The movement of the hill was slow, and the gradual leaning outwards of the detached mass actually produced a state of longitudinal tension in the masonry of the tunnel near its mouth. Alarming circumferential cracks opened in the masonry, which gradually increased as time passed. If unchecked, the movement finally resulted in the fall of the masonry and a big landslip on the face of the hill. Fortunately, this characteristic of shale tunnels declared itself markedly in the first tunnels attacked, and ample warning was thus given. The remedy was simple. A massive portal prevented the masonry from being pushed outwards. If built too close to the face of the hill, the portal was liable to damage when, as often occurred, a slip took place. It was decided, therefore, to build the face of the portal well outside the face of the hill. The first few lengths of masonry were built in the open and were well covered with spoil. The portal was therefore scarcely distinguishable from an extension of the tunnel. This form of portal was well adapted to resist a longitudinal push, and an external landslip merely resulted in the spoil spreading itself harmlessly at its natural slope over the portal. Once the shale had been fairly entered and the portals secured, no abnormal difficulties occurred. Crown bars would sometimes be splintered by pressure, and pockets of shale would fall into the workings, but the staff quickly became expert in dealing with such occurrences.

Michni tunnel, to which reference has already been made, lies high up, through a steep ridge of shale which gave no sign externally of containing water. Yet as soon as the headings were started, a serious state of affairs was disclosed. The portion of the hill tunnelled contained wet, muddy shale. The occurrence of large quantities of water at this height, and indeed the existence of this steep ridge made apparently of sloppy mush, is mysterious, and it

Digitized by Google

is probable that the railway unluckily passed through an underground reservoir of limited extent. Support is given to this view by the undoubted partial drying-up of the tunnel during its 4 years of construction, due to vigorous drainage down the 1-in-25 gradient. Fortunately, the bad portion of the tunnel was only 800 feet long. The use of a shield and compressed air would perhaps have been justifiable, though it would have been expensive for a short tunnel in a remote place. The Author decided to obtain extra working-faces by driving two adits, and to attack the tunnel with normal methods. Progress was terribly slow at times, and there were many temporary failures and disappointments. The working-conditions were deplorable, owing to the incessant rain of water and mud, but ventilation from the compressed-air drilling-plant and electric light alleviated them somewhat. The 800-foot portion was lined completely, with an invert, the lining consisting of six or seven rings of brick set in Portland-cement mortar.

In Galo Tara tunnel the heading was driven without incident through very hard slaty shale. The dip and strike were favourable, and the Author decided to enlarge the tunnel to full size without timbering the roof. All went well throughout the tunnel except at one place, where the roof caved in as soon as the heading was enlarged. At this place a pocket of soft shale overlay the hard shale, and, on clearing the debris, a large domed cavern was found to have been formed. Attempts to timber this cavern failed, and successive collapses enlarged it until daylight was visible 70 feet above. The shale continued to move, and eventually a sort of shaft or crater became stabilized. The tunnel was, with some difficulty, taken through this section by cut and cover, a cushion of 20 feet of earth was piled on the tunnel arch, and it was assumed that all was well. The sides of the tunnel were unlined. About a year later, following a great storm of rain, one side of the shaft, and perhaps one side of the tunnel, collapsed, destroying the tunnel-arch below for a length of 20 feet. Repairs were effected by working down the shaft or crater, whose sides were permanently supported by flying masonry arches at intervals.

Ingersoll-Rand petrol-driven air-compressors, each capable of working two drills, proved satisfactory and were easily portable, some being dragged into very inaccessible places. Since seventy or eighty working-faces were in progress at one time, scattered over a length of 26 miles, it was hardly possible or desirable to provide mechanical drills for all, and many of the tunnels were drilled by hand. It is remarkable that, under Khyber conditions, there was little to choose in cost between a hand-drilled and a

Digitized by Google

machine-drilled tunnel. In speed, however, the machine drill had an easy lead. Many tunnels were lit by electric light. Spoil was removed by hand-pushed 2-foot-gauge tip wagons of 25 cubic feet capacity.

The cheapest tunnel is one in hard rock, excavated without the use of timber and having only its roof lined with masonry. Such a tunnel gives no anxiety, and work can be organized to proceed smoothly and economically. At the other extreme lies the difficult tunnel in wet, soft strata, whose cost is increased by the use of large quantities of timber and by massive masonry lining in roof and sides, as well as by delays. Again, a tunnel on a 7-degree curve is much wider and therefore more expensive than a straight tunnel. On the Khyber Railway one tunnel might be all on the straight, another all on a curve, another partly straight and partly curved. One might be in bad, another in good, and a third in variable ground. There was thus ample room for variation in the cost of individual tunnels, and not much would be learnt by one unfamiliar with all the circumstances from a mere statement of the cost per linear foot. It is hoped, therefore, that the figures given in the Appendix, which are derived from the averages of similar groups, will be useful. In specially favourable cases, costs as low as Rs. 300 per linear foot were reached, and in specially unfavourable instances the cost was Rs. 788 per linear foot.

Bridges.—The waterways were calculated by the method described [1] by Colonel Hearn. At the end of July, 1925, when all the bridging was complete, the Khyber district was devastated by a storm of great intensity and, according to the tribesmen, of very rare incidence; $3\frac{1}{2}$ inches of rainfall in 2 hours was experienced at Landi Kotal. The result was a complete vindication of Colonel Hearn's method: many bridges and culverts ran to their full capacity, but no damage occurred, except some embankment washaways due to side scour by the main Khyber nullah, which overflowed its banks in places. Unfortunately, no direct observations of flood-velocities could be made, as the storm occurred at night.

The largest bridge consists of four spans of 40-foot girders and one 80-foot girder on piers 80 feet high. The foundations were dry and presented no difficulty. The main Khyber nullah is crossed seven times by means of bridges of two or three 40-foot girder spans (Figs. 11, Plate 1). The average slope of the nullah is 1 in 50, and there is no vegetation to moderate floods, which sweep down with great force. It was therefore decided to carry the pier and abutment foundations down below apparent scour-level,

[1] Minutes of Proceedings Inst. C.E., vol. ccxvii, p. 267.

Digitized by Google

and also to floor the openings completely with a 9-inch floor of concrete provided with deep drop walls upstream and downstream. The flood, which brings with it masses of debris, has therefore little opportunity to attack the foundations.

In one particular detail of design some degree of uncertainty was felt. There are two bridges on piers 60 to 80 feet in height. The Indian bridge rules require design to take account of stresses due to the braking or deceleration of trains while crossing bridges, which may theoretically throw considerable stress on the girders in a direction along the centre-line of the bridge. If this is transmitted to the masonry, the resultant force is deflected to an extent which brings it to an alarming distance from the centre of the base in the case of a high pier. One of the above-mentioned bridges was sited (Fig. 12, Plate 1) in a ravine, so that the down-gradient abutment could be embedded in rock. The girders are free to move longitudinally, but are separated by wooden blocks, so that if they start to move downhill under the action of creep or braking stress, they will merely crowd against each other and at the lower end press against solid rock. In the other bridge the approaches are on banks, so that the same expedient is not possible, though perhaps similar blocking might be useful. This plan is perhaps not altogether ideal, but some method of keeping awkward horizontal thrusts off the masonry seems desirable. It may of course be argued that most of the braking stress is taken up by the permanent way on the bridge and its approaches, and that a moderate increase in the masonry of the bases of the piers will do all that is required. Both bridges are on steep gradients of 3 and 4 per cent., and the descending train is often checked by a rapid deceleration, so the matter appears to require elucidation.

Retaining-walls.—There are four large retaining-walls and a few small and unimportant ones. The section employed for all surcharged retaining-walls is an isosceles triangle having batters of 4 to 1 (*Fig. 13*). Where a wall was not surcharged, but was carried up to formation-level, with the consequence that the load of a passing train became of importance, the back batter was increased to 3 to 1.

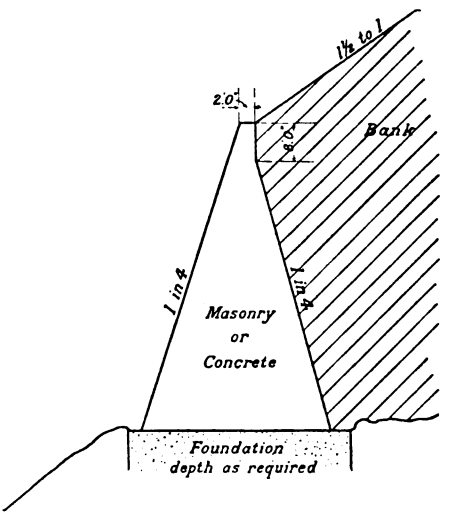
Permanent Way.—The permanent way is of British Standard section 90 lbs. per yard, on deodar sleepers up to Landi Kotal, and on Lines cast-iron sleepers from Landi Kotal to Landi Khana on the 1-in-25 gradient. There are thirteen sleepers per rail-length of 36 feet on the straight, and fourteen on curves. Joints are staggered on curves. Nearly all curves are 7 degrees, superelevated 3½ inches, and approached by cubic-parabola transition-curves 105 feet long.

Digitized by Google

Stations.—Owing to the insecurity of the country, the usual station-buildings and quarters could not be used. At each station of importance is a fortified walled enclosure containing all offices and quarters, which is defended by towers at opposite corners.

Motor Transport.—The vehicles used comprised twenty 1½-ton Fiat lorries, five 3½-ton Fiat lorries, and twenty Sentinel steam-wagons. The 1½-ton lorries had pneumatic tires and were fast, powerful vehicles. They were used principally for distributing

Fig. 13.



STANDARD SURCHARGED RETAINING-WALL.

staff on the work, and gave great satisfaction. The performance is summarized by the following figures :—

Average mileage during period of maximum work	8,500 miles per month.
Average cost per mile during same period, including repairs	15 annas per mile.
Petrol-consumption during same period	9 miles per gallon.

When the rails were laid, some of these vehicles were fitted with railway wheels to run on the track, and gave good service.

The 3½-ton Fiat lorries were not a success. They racked themselves to pieces on the long hills in the Khyber, and were laid up and sold.

The Sentinel steam-wagons were very successful. Fifteen were

Digitized by Google

5-ton vehicles with tipping bodies, and the remainder were of the 6-ton type with fixed bodies. They took their full load and an occasional overload without difficulty, using Bengal best locomotive coal. They took a full load up the Pass and usually returned empty; thus the average load was a little more than 2½ tons for the round trip. They worked on an average 22 days in the month, the remaining days being taken up with boiler-washing and repairs. The following figures are of interest:—

Average mileage worked during period of maximum work	8,500 miles per month.
Average ton-mileage during same period . .	23,000 ton-miles per month.
Average cost per ton-mile during same period, including repairs	15 annas per ton-mile.
Coal-consumption per mile	40 lbs.

The cost of bullock-cart transport was 9 pies per maund per mile, equal to R. 1.5as. per ton-mile.

Personnel.

The survey was carried out by Colonel G. R. Hearn, C.I.E., D.S.O., R.E., Assoc. Inst. C.E., as Engineer-in-Chief. On construction being sanctioned he was appointed Engineer-in-Chief of the Khyber Railway Construction. Colonel Hearn remained during the difficult early period to initiate and direct operations until November, 1922, when he was succeeded by Major E. P. Anderson, D.S.O., R.E., Assoc. Inst. C.E., who held charge up to February, 1924. The Author was employed from the commencement of construction, first as Executive Engineer, and later in succession to Major Anderson in February, 1924, holding charge up to September, 1925.

The Paper is accompanied by fourteen sheets of tracings, from which Plate 1 and the Figures in the text have been prepared, and by the following Appendix.

Digitized by Google

APPENDIX.—TABLE I.—TYPICAL

	Soft Shale on a Curve.	Rs.
Heading.		50
Enlarging	Excavation 550 cu. ft. @ Rs. 125 per 1,000 cu. ft. = Rs. 69	
	Less charge for air-drill . . . . . ,, 15	54
	Explosives.	
	5 lbs. gelignite	12
	10 detonators	
	40 lin. ft. fuse	
	Compressed-air drills	25
	Timber, miscellaneous.	35
	Lighting.	2
	Miscellaneous	5
		133
	Supervision 20 per cent.	27
	Total	160
Lining .	*Half Lining* (roof segment only).	
	Masonry 60 cu. ft. = 900 bricks @ Rs. 45 per 1,000	41
	Transport of bricks @ 1 anna per maund per mile for 3 miles	15
	Mortar 21 cu. ft. @ R. 1 per cu. ft.	21
	Transport of mortar	6
	Masons	18
	Water	5
	Lighting	2
	Centering	5
	Packing, concrete, moving centering and miscellaneous	20
		133
	Supervision 20 per cent.	27
	Total	160
	Full Lining (lined to 3 feet below formation-level, without invert).	
	1·9 × cost of half lining	304

Digitized by Google

COST OF TUNNELS PER LINEAR FOOT.

Limestone on a Curve.	Rs.
	70
Excavation 520 cu. ft. @ Rs. 200 per 1,000 cu. ft. = Rs. 104	
Less charge for air-drill . . . . . ,, 20 . .	84
Explosives.	
10 lbs. gelignite	
20 detonators	24
80 lin. ft. fuse	
Compressed-air drills.	40
Lighting	2
Miscellaneous	5
	155
Supervision 20 per cent.	31
Total	186
Half Lining.	
Concrete 60 cu. ft. @ Rs. 160 per 100 cu. ft.	96
Lighting	2
Packing, moving centering, etc.	5
	103
Supervision 20 per cent.	21
Total	124
Full Lining.	
1·9 × cost of half lining	236

Digitized by Google

TABLE II.—SUMMARY OF TYPICAL TUNNEL COSTS ON CURVE.

Rupees per Linear Foot.

	Soft Shale.			Limestone.		
	Half Lined.	Fully Lined.	50 Per Cent. Half Lined. 50 Per Cent. Fully Lined.	Half Lined.	Fully Lined.	50 Per Cent. Half Lined. 50 Per Cent. Fully Lined.
Heading	50	50	50	70	70	70
Enlarging	160	160	160	186	186	186
Lining	160	304	232	124	236	146
Total	370	514	442	380	492	402

NOTE.—Cost of tunnels on the straight is about 15 per cent. less than on curve.

TABLE III.—TUNNELS.

Miscellaneous Statistics (Averages.)

	Shale.	Limestone.
Average overall progress . . . . . feet per day	0·45	0.55
Gelignite . . . . . lbs. per foot	5	10
Average charge . . . . . lbs.	0·26	0·28
Bricks per linear foot	2,670	—
Concrete per linear foot . . . . . cu. ft.	—	62

Digitized by Google

(Paper No. 4590.)

"The Survey and Construction of the Khyber Railway."

By Colonel Gordon Risley Hearn, C.I.E., D.S.O., R.E., Assoc. Inst. C.E.[1]

The project of establishing railway communication with Afghanistan is by no means new. During the second Afghan War in 1879, Sir Guilford Molesworth examined the possibility of running a metre-gauge railway through the Khyber, but railhead was then only near Attock. In 1890, Captain (afterwards Major-General Sir) J. R. L. Macdonald ran a survey from near Kam Dakka down the gorge of the Kabul river. In 1898 a survey for a narrow or metre-gauge railway was made in the Khyber Pass as far as Landi Kotal. Railhead was then at Peshawar. In 1904 the survey of a "cut-off" via the Loi Shilman valley, to shorten the river route, was made by Captain L. E. Hopkins, R.E. In 1905 the construction of so much of the Kabul river railway as was common to both routes was commenced; this came to an abrupt close in 1909, when the way which had been laid was pulled up and the girders were withdrawn. The only real advance in the last 20 years or so before 1919 was the extension of about 9 miles to Jamrud, the fort guarding the exit from the Khyber Pass, in 1901.

In May, 1919, the third Afghan War broke out, the Khyber was occupied, and two brigades had advanced as far as Dakka, when it was desired to follow them up with a line of railway. The Author was instructed to reconnoitre a cart-road running through the Mullagori and Shilman country (north of the Khyber) to Landi Kotal, with a view to lay a 60-centimetre track as much on the road as possible, to save time. After a hasty trip in a howling dust-storm, he obtained a tribal escort and made a reconnaissance, going also into the Loi Shilman valley and seeing what he could of that route.

[1] Now Col. Sir Gordon Hearn.—Sec. Inst. C.E., Dec. 1926.

Digitized by Google

He was also able to look down on the Kabul river route and see many of the abandoned works.

The Mullagori–Shilman road looks bad enough on the map, but not one in three of the twists and bends can be represented, while the rises and falls are not confined to those in the deep and narrow valleys of the Kam Shilman and Shahidmiana, but nearly every steep place is thus avoided. A few of the salient levels may be mentioned:—Shahgai Thana, 1,134; Lowara Mena, 2,500; Shahidmiana, 1,150; turn into the Kam Shilman valley, 2,200; Kam Shilman rest-house, 1,750; Haidari Kandao Pass, 4,035; and Landi Kotal, 3,500 feet above sea-level.

The Author had no hesitation in condemning this route, but at the same time he pronounced the Khyber feasible, provided no objection were raised to reversing-stations. The question was deferred for a while, but a survey was ordered for a broad-gauge adhesion line at the end of July. By this time the Author had been able to carry out some further reconnaissance, part of which with the aneroid barometer gave some excellent results. Two parties were employed, both the reconnaissance and surveys being completed in 4 months over a distance of nearly 40 miles.

The Paper gives a description of this survey, with information gained during construction of the 5-foot 6-inch gauge line under the Author's direction. The alignment adopted has proved well justified by results.

Topography.

The best appreciation of the topography of Northern Afghanistan is to be obtained by the study of a modern "layered" map. The light-coloured Vale of Peshawar is separated by a comparatively narrow strip of darker colours from the light colours of the valley of the Kabul river in the Jalalabad Province. It is not for some distance west of the provincial capital that the dark colours show ground of higher altitude merging into the reds which commence at 6,000 feet. It is, however, with the eastern portion of this tract that a railway giving access to this land-locked country is concerned.

Peshawar and Warsak, where the Kabul river debouches from the barrier range, both lie about 1,150 feet above the sea. It is not possible to water the Cantonment from the Kabul river canal starting near Warsak. Dakka, or rather the fort of Sherabad, lies only 1,370 feet above the sea. This comparatively small rise occurs in about 40 miles, measured round a great loop to the north of the Kabul river, and it is obvious that easy gradients are obtainable by following the river.

Digitized by Google

Jamrud, outside the Khyber Pass, is at an elevation of 1,500 feet, necessitating a gradient of 1 in 80 for the latter part of the 9-mile run from Peshawar. Landi Kotal, the summit of the Pass, is 3,500 feet above sea-level. Landi Khana, about 1 mile inside the boundary, is about 2,400 feet, so that there still remains a drop of more than 1,000 feet to Dakka from this point, in a distance of about 9 miles. On the other hand the bee-line distance from Peshawar to the boundary is about 28 miles only, and it does not require more than 36 miles in all by the Khyber route, whereas the Kabul river route up to the boundary would require 54 miles. The difference in mileage must be set against the advantage in gradient, but there are weightier considerations.

An alternative proposal was to use the Kabul river route but to cut off the greater part of the big bend of the river by turning up the Loi Shilman valley at a point where the neck of the loop is about 10 miles wide. The pass at the head of the valley, known as the Shilman Ghakke, is only 2,447 feet above sea-level, 1,000 feet lower than Landi Kotal, but the fall of 1,100 feet to the river is abrupt in a distance of 3 miles, and the eastern access to the cut-off is complicated by a narrow deep valley, the Kam Shilman, also by the unfavourable orientation of the Loi Shilman valley, which is very tortuous in the lower part.

A suggestion to tunnel right through the range is disposed of by the fact that the distance from Jamrud to Landi Khana is 17 miles in an " air line." It would require a tunnel about 6 miles in length to pierce the watershed between the Kam Shilman valley and Landi Khana, while the gradient of approach would be equally severe, though shorter than those through the Khyber Pass. Both these ideas may thus be disposed of once for all, though they were seriously advanced at one time.

The Kabul river has in parts a narrow strip of land on one or other bank, said to be frequently flooded. For a considerable length it flows in gorges where the steep hillsides come right down to the water with frequent very sharp bends and turns. The current is swift, and there are several whirlpools, making a crossing to the farther bank dangerous. The nature of the gorge in places may be judged by the fact that the estimated cost of formation and bridging on the last 2½ miles of the now abandoned river railway exceeded 28 lakhs of rupees (£190,000). The following 2 miles would have cost about as much. That railway stopped short of the junction of the valley of the Kam Shilman, to cross which on the Loi Shilman cut-off a viaduct 140 feet high was proposed.

Digitized by Google

A railway through the Khyber Pass was no light proposition, as will be seen from the detailed description to follow. Perhaps the general public imagine the "Pass" to be a short gorge or valley between high hills, but the facts regarding distances and heights already given will disabuse the engineer of this idea. However, with all its difficulties there are 6½ miles of comparatively easy going in the upper Khyber valley approaching Landi Kotal. Here there is some population and some cultivation, and the Pass is a line of communication which has a history extending back for centuries.

Geology.

The geological aspect of the problem is of great importance, and in previous reports it does not appear to have received attention. The Author had this factor brought prominently to his notice during a reconnaissance for a railway in the tracts surrounding the Takht-i-Sulaiman mountain farther south. Consequently he observed the geology closely and found that the general direction of the strike is east and west, while the dip generally is to the north at an angle of about 40 degrees. This continued as far as he could see north of the Kabul river.

During the construction it was found that there were local faults and folds, for instance, in the region of the Changai valley. Here the removal of a heavy limestone cap has apparently caused the upheaval of an anticline, so that the northerly dip along the Changai spur becomes a southerly dip on the south slopes of the valley. This is a decided advantage, as the most is made of this valley.

The rock consists mainly of a thinly-stratified, hard, argillaceous shale, which, in places, has been much shattered and is treacherous, but, on the whole, on account of the dip is able to stand at a steep angle on the northern side of cuttings. It was therefore important to locate on northern slopes as far as possible, so that any slides would occur on the "short" slope of a cutting. Where it was necessary to follow the southern slope of a hill, the line was located out as far as possible. Actually in places this might have been done to a greater extent.

Here and there this shale, having been subjected to pressure and heat, has been altered into what the Author would prefer to call schistose rock, although a geological opinion terms it "quartzite." This rock is not always stratified, but occurs in pockets and is much harder. In a few places the shale, generally perfectly dry, has been converted by water into a soft black substance resembling

Digitized by Google

coal. This was found in two tunnels, one being particularly bad throughout. The presence of water in this generally arid region is mysterious.

Comparatively narrow bands of limestone occur sporadically among the shale, one such being traceable from Ali Masjid eastward to the end of the Changai spur. The Ali Masjid gorge consists of limestone thickly stratified and fissured, and, as usual on the frontier, the stream traverses this limestone at right angles to the strike, i.e., from north to south. This limestone forms a heavy cap on the high range bounding the Khyber route to the north. Considerable masses out-crop to the north of the upper Khyber valley, and the range to the south consists largely of this limestone. Large masses occur in the Kam Shilman valley owing to the dip, and there is another heavy cap on Tor Tsappar farther north.

It remains to notice the moraines of boulders and clay which form the lower slopes of most valleys, and the loose flakes, pebbles, and boulders which form the stream-beds and make them highly absorbent.

Khyber Route.

The Khyber stream rises in the hills to the north of Landi Kotal, the summit of the route. The stream flows in a bed formed in the debris of the valley, here a mile or more wide, and in the upper part tends to hug the northern side; but, as the valley becomes narrowed by the hills east of Zintara, it sets now against one side now against the other, causing a "stiff" alignment to cross it several times, until the Ali Masjid gorge is reached. Where side valleys are formed by the receding of the hills at two points, clusters of Zakka Khel villages stretch right across at Sultan Khel and Nikki Khel. The upper part of the valley is terraced and cultivated, but the rainfall is light.

The Ali Masjid gorge is most uncompromising, almost vertical cliffs of limestone of a height extending to more than 2,000 feet, coming right down to a narrow stream. The bottom of the gorge is occupied by a road on each bank, while a ropeway also is threaded through. At the end of the gorge the stream hugs its right bank, leaving a low shelf, liable to flooding, occupied by the camp nestling against a high spur on which are hut barracks. A deep ravine separates this spur from another, and immediately east of this latter spur there is a deeply-cut amphitheatre into which the two roads bent sharply. They are now carried on the railway bank.

Digitized by Google

The stream now flows south for more than 2 miles, leaving a bare plateau, the Shahgai heights, on its left, and then trends eastward, emerging by the Jaba Tangi to the plains about 3 miles south-west of Jamrud Fort, which, turning north-west, it passes on the east in a broad bed. In the lower part the gradient of the stream is comparatively easy, about 2½ per cent., but the proximity to the Bazar valley to the south, and the easy access by the Chora stream draining that valley, placed this portion of the route out of the question politically. It must also be realized that in such a narrow valley the location of crossing stations causes a great loss of fall, which cannot be made up by development, and therefore the gradient would probably have been increased to 3 per cent. in any case.

The main Khyber stream was followed by British forces during the first part of the first Afghan War, but a road was then constructed by Mackeson across the Shahgai plateau and down the southern slopes of a subsidiary basin, which emerges from a narrow opening between Sarkai and Nurai, east of Jamrud. This opening has been termed the "jaws" of the Pass, and from here to Jamrud is a distance of nearly 3 miles over a fan-shaped moraine of debris. The stream, however, emerging from the "jaws," takes a north-westerly course to the Kabul river.

Turning now to the westerly descent from the Landi Kotal summit, it should be observed that the principal stream rises among hills to the south, and although fairly straight from Landi Kotal to Michni Kandao, has several waterfalls, so that in 1½ mile the bed is 450 feet below the summit. This is bad enough, but then there is a complete erosion of the country, so that in the next ¾ mile the drop is no less than 500 feet. Such an impression is made on the onlooker that the Author has been informed on good authority that Lord Kitchener pronounced the descent "impossible." The northern slopes of this basin are benched with two roads, which attain the camp at Landi Khana with some difficulty on a gradient of at least 1 in 17 and with many bends.

Reconnaissance Survey.

When a problem presents itself every few hundred yards, with complications due to causes not local, and with political or military considerations to meet, it would be tedious to go into these matters over the whole route. The Author will confine himself to the ascent to Shahgai, the problem of the Ali Masjid gorge, and the descent from Landi Kotal.

Fortunately an excellent map was available, but only a general

Digitized by Google

estimate of relative heights and distances was possible. The map had to be supplemented by a rough survey with compass and chain along the existing roads, aneroid-barometer levels, which turned out wonderfully accurate owing to the experience of the Author in this subject, plane-table intersections, and clinometer observation. On the ascent to Shahgai a tacheometer was used, for the projected alignment lay over rough hillsides unsuitable for compass and chain. The result was satisfactory, and a month's work on both ascent and descent was sufficient to produce a predicted section differing slightly from that given by more serious work.

It may be mentioned that a political condition laid down was that the line should nowhere lie more than ½ mile south of the road. The promise was readily given, and the widest deviation is only ¼ mile. But this condition put out of court the 1898 survey, which swung south more than 1 mile and in addition was on a 4-per-cent. gradient.

The Author succeeded in obtaining a 3 per cent. gradient on the ascent to Shahgai, but less than 4 per cent. was not possible on the descent to bring the terminal station within the boundary. Reversing stations in pairs are necessary on both ascent and descent, but this was announced and accepted before any serious work was started and as the result of reconnaissance only. These reversing stations can be eliminated in the future if required by development of traffic in settled conditions. A single line will then still be sufficient for many years.

Bagiari to Shahgai.—The distance in an "air-line" from the "jaws" to the edge of the Shahgai plateau is 2 miles, with a difference in level of 750 feet. A 3-per-cent. gradient cannot quite make 150 feet a mile, if crossing stations have to be interpolated, so that the necessity for development was evident, and this could only take place by winding across or by doubling back with "spirals" or otherwise.

Looking from Bagiari Fort just inside the jaws the streams can be counted on the fingers of the left hand. The thumb is Medanak, the first finger Kafirtangi, the middle finger Changai, the third finger Jahangira, and the little finger Rai Kila. The catchment-area is decidedly "balloon-shaped."

The spur followed by Mackeson's road runs from Fort Maude to Fort Bagiari (between middle and third fingers). Both the motor-road and the regraded cart-road on Mackeson's general alignment adhere to this spur, fortunately. The gradients are 1 in 13, with a short and bad piece of 1 in 9. The Author, however, noticed at once the Changai spur (between first and middle fingers), which unlike the Bagiari

Digitized by Google

spur falls comparatively gently to 2,300 feet, and then only very sharply at its end. Very early aneroid-barometer levels and a few clinometer observations from the motor-road established the possibility of a reversing-station at the end of the Changai spur, and obtained the height of a waterfall, recognized then as a controlling point on the spur.

There is a ridge extending from the Shahgai plateau to Barley Hill, and it was calculated that an alignment piercing this ridge in tunnel would just enable sufficient height to be made to obtain a crossing-station on the plateau, an important point for several reasons, enabling the station to be extended if necessary. Without previous experience the treating of this ridge as a false summit might not have been recognized as the right thing to do. It was not so treated on the 1898 survey.

Thus, between Shahgai station and the first (Changai) reversing-station, 3½ miles of line gave 405 feet of fall. There remained as much again, even by keeping the formation above the stream-bed at the jaws. To reverse back along the southern face of the spur gave no room, as the bed of the stream rises very sharply, and 1,600 feet would be necessary for vertical curve, cross-over, and sidings. Therefore, the line was taken by a tunnel through the spur into the Kafirtangi valley. It was at one time thought that sufficient distance could be made available without another reversing-station, but this was wrong. So a second reversing-station was made on the spur, and the remainder of the distance was obtained by circling round a hill into the Medanak stream and running across the general direction. Thus 340 feet of fall is obtained in an "air-line" distance of ¾ mile, without any extraordinary works. There is nothing heroic, but the greater part of the ascent involves continuous heavy work. The rest of the way to Jamrud, however, becomes comparatively light. It is the Author's experience that it is always best to "lump" the heavier work and get down as quickly as possible, instead of having to continue desperately contouring the outer features, thus getting away from the objective. Also, it is always necessary to work out the alignment from the summit downwards, taking account of controlling points.

The Ali Masjid Gorge.—The line, having reached the Shahgai plateau, finds its access to the gorge barred by the two spurs previously mentioned, which cause the two roads to make a long detour. Then comes the crowded gorge. Very early in the reconnaissance the Author and an assistant climbed the hill crowned by the fort and inspected the cliffs, deciding that a high-level line was

Digitized by Google

satisfactory. Subsequently, on comparing this reconnaissance with the 1898 survey, in which the line was kept low, made before the motor-road or the south road was constructed, it was found that the amount of tunnel was very little increased, while the avoidance of interruption of the roads was complete.

From Shahgai onwards the gradient has been reduced to 2½ per cent., except at Sultan Khel and Landi Kotal, where the gradient can be negotiated as a "velocity grade." The first is an example of the difficulty of getting in a crossing-station length when the general fall of the valley is approximately equal to the gradient. Through the upper portion of the Ali Masjid gorge the line is level, an advantage in view of the very high winds at certain seasons, on account of which the line is brought down to the valley-floor at the upper end of the gorge. The wind at certain times of the year makes instrument work impossible in all gorges leading down from the highlands of Afghanistan.

Landi Kotal to Landi Khana.—The fall mentioned of 450 feet in 1½ mile and of 500 feet in the next ¾ mile, with only 1 mile left to the boundary, was no light problem to solve. Here again, the important point was to get down and not to have a line contouring the outlying buttresses of Spinatsuka. The reconnaissance survey with simple instruments was very useful.

In the upper part the two roads promised to be very embarrassing, but fortunately they keep to opposite sides till near Michni Kandao, and still more fortunately the motor-road at a critical point rises unexpectedly to escape a cliff. A certain amount of interference with the roads was inevitable, but the finished re-alignment will be an improvement, due to the elimination of many bends.

The first scheme to get down was to introduce a "spiral" tunnel near Michni Kandao, where the confluence of the Tangi ravine caused the main stream to open out somewhat. This was perfectly feasible and would have caused a gain in fall of 180 feet, but the rough survey showed that this advantage would be lost by having to tackle the big spurs above the roads at the wrong level altogether. To introduce another "spiral" and curve back into the basin would have led the line on to the southern slopes, which are most uncompromising, and even so would not get the line down until somewhere over the border.

The alternative finally selected was to get away from the basin or "scoop" below Michni Kandao as soon as possible, to tunnel the spurs as high up as possible, and to reach the Tora Tigga valley which joins the main valley below Landi Khana. Locating a reversing-station as high up the valley as possible just brought the

Digitized by Google

level to a far from ideal, but yet the best, piece of ground to be found unoccupied at Landi Khana.

There are not many feet to spare in this zigzag, but this plan turned out well enough, and a view of the sweeping curves in the Tora Tigga shows how well the 818-foot radius curve suits the main features. The quantity of earthwork is deceptive and far from light, owing to the deep narrow ravines to be crossed. Still, there is comparative freedom from tunnels, which is just as well, since the length of tunnel in any case mounts up to 6,364 feet in a distance of 5½ miles.

Curvature.

In such extremely difficult country the temptation to introduce sharp curvature is high, but the Author maintains that skilful location gains from adhering to the easiest curve in reason. The loss of fall by the compensation necessary for sharp curvature is very serious. At one swing of the deliberative pendulum a 2-foot 6-inch gauge was proposed. The Author never believed in this, but extended the scope of the contoured belt to include a possible alignment. The result was not unforeseen. An additional distance of 2½ miles on the ascent really got the line down no better, and the 100-foot-radius curves did not eliminate a great deal of heavy work. No curve in reason would have suited the sharp spurs, and tunnelling does not increase in cost in proportion to the area of finished section.

On heavy gradients the wheel-base of the engine must be increased to draw the load. However sharp may be the curves for which a locomotive is designed, there is a practical limit, which the Author believes to be 800 feet for an eight-coupled locomotive, whatever the gauge may be. Curves of 573 feet were used on the Kabul river route, but the easier gradient would have enabled a six-coupled locomotive to be used. At the same time the Author is of opinion that the standard type of Indian 0–6–0 locomotive is too stiff for this latter curve.

The proportion of curvature is 50·6 per cent. of the total length, with 176 degrees per mile. Only 3·77 miles, or 13·58 per cent., is on the level.

Preliminary Survey.

The tacheometer was used extensively on this work, and considerable saving of time was obtained by some reduction diagrams got out by the Author, enabling differences in height and total reduction of distance to be read off direct. In the Author's opinion,

Digitized by Google

too great care is taken in reducing to two places of decimals heights which cannot be plotted to a pin-point, and between which the interpolation of contours cannot be judged exactly. The rough reconnaissance survey saved a good deal of unnecessary contouring, the stations being chosen quite near to the projected line. They were both levelled and check-levelled before the tacheometer was set up at them. During reduction of levels and transfer to the plan in the office, the plane-table was used in the field for contouring a finished sheet—a great improvement over office contouring. The predicted section differed little from that obtained from the reconnaissance survey, and, except where the location was deliberately changed before or during construction, the levelled longitudinal section fulfilled all expectation. Most of the Ali Masjid gorge was surveyed by tacheometer from stations on the opposite hillside.

Location.

Little need be said on this operation, although it was very arduous. Subtense work was necessary in parts, and even triangulation, but the tunnel-headings all met reasonably well, proving the general accuracy of the work.

An example of the levelling necessary may be given. The curve at the turn of the Changai valley is 1,704 feet long, and the aggregate rises and falls in levelling total 652 feet. This curve was realigned during construction.

The total length is 27·75 miles, and it is interesting to note that the distance to Landi Kotal is slightly less than the road distance, although that is perhaps not very accurately measured, after many shifts.

In drawing the sections of steeply-graded railways, if the datum line is continuous, the section has to be continually broken. The Author adopted the system of breaking the datum, which is stepped. It is a perfectly easy matter, when preparing the sections in 3-mile lengths for binding, to trace them with a horizontal datum.

Work Numbers.

The construction work was divided up by "work numbers" corresponding to the work-order system of a workshop. This facilitated matters considerably, compared with the system of allotting consecutive numbers to tunnels, bridges, culverts, retaining-walls, etc., respectively. It is easier for engineers to remember, for instance, where the "major" bridge in work 19

Digitized by Google

lies, than to remember where major bridge No. 13 lies, while any reference to chainage or mileage in correspondence or accounting becomes unnecessary. A large-scale drawing of a "work" is often useful. All tunnels were given special names also.

The preparation of and constant reference to the construction estimate was much facilitated by this system, while allocation of expenditure to each work-number was also simplified. The Engineer-in-Chief was able to watch this expenditure by the card-index system, the totals under various items of work being plotted on squared cards and expenditure blocked out as incurred. This graphic method is far more effective than pages of figures in ledgers.

The use of vertical filing both for correspondence and for plans was very effective, and the work-number system fitted in very well. A minor improvement on the usual system of allotting serial numbers only to plans was that the revised plans were numbered second, third, or fourth editions, and the out-of-date plan was then transferred to a record drawer. If a plan was required, it could be produced in a few minutes, instead of after reference to a serial register and search in a drawer. Vertical filing of plans should become universal.

The drawing-office was designed with specially large windows, the total area of glass in windows being rather more than one-eighth of the floor-space. The ferro-typing work was done entirely by electric light in the winter, when many days are cloudy, although rain does not often fall. Even in the summer the speed of output was an advantage.

Design of Works.

It is not proposed to go into any detailed description of the features of the various works, but only to notice a few special points. The Khyber Railway is designed to the "Recommended Dimensions" of 1922 for the 5-foot 6-inch gauge. The bridges were designed for the 1916 standard (now called Standard Three) for the heaviest locomotives.

The slopes of banks stood at 1 to 1½ as a rule. Some of the banks were of considerable size, one in work No. 26 containing 4 million cubic feet, while the one in work No. 85 had a maximum height on the centre line of 75 feet, and carried both of the roads as well. Work on these banks was slow, about 100,000 cubic feet per month being a normal rate of progress. In work No. 26 steam-shovels and light locomotives were used, and progress could be kept up in spite of the hardships of the month of Ramzan. There were two heavy banks in the Tora Tigga section.

Digitized by Google

Cuttings did not stand so well as was expected, and the want of experience of the labour in such work caused waste of explosive, mostly gunpowder. The cost of earthwork generally was very high compared with the estimate, but more was thrown to spoil than was anticipated, and higher rates had to be given, besides charging up incidental costs peculiar to the locality.

Two inclines were used, one worked by steam hoist and the other by gravity.

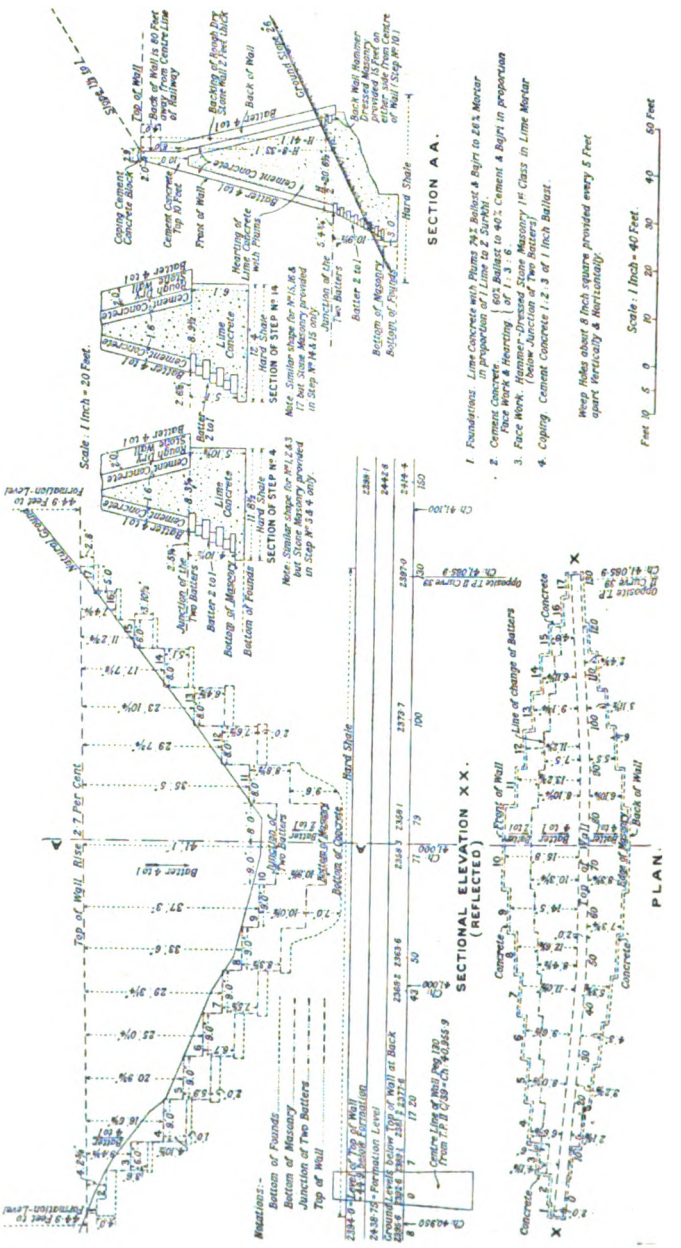
Besides the diversions mentioned above, there were other important road-diversions; but great care had to be taken not to throw roads out of use. The roads at such diversions were usually much improved, and this added to the cost. There are only seven level crossings of the motor-road in the 27·75 miles of line, and this is one of the features of the location.

The diversions of the streams were in some cases important. The Kafirtangi stream was dammed and diverted by cutting through a spur. This worked very well in the flood of May, 1923. The Changai stream was taken through a spur in a tunnel, and the actual bed was filled by a bank, thus saving a viaduct; and this worked well in the same flood, except that the outfall was damaged. At Zintara exigencies of alignment and level demanded a considerable diversion of a stream-bed which crossed the line at a higher level than formation. This also worked well in July, 1925.

Drawings of a retaining-wall on a side slope are given in *Figs. 1*, and attention is drawn to the buttresses at the foundation whereby the resultant thrust is kept well within the masonry. The foundation plan may be specially noticed. Another feature is that a thinner wall has been employed, where surcharged and where the line is at some distance, owing to the "line of rupture" cutting the line of pressure of superimposed load. Some of these walls were built in mass cement concrete, some in lime-surkhi concrete with a facing of stone, which was difficult and expensive to dress, or of cement concrete. Weep-holes were liberally provided, and hand-packed stone was placed at the back for drainage. Front batter was given also to wing walls and abutments of bridges so as to utilize the mass to the best advantage and to reduce the section.

Most of the small arched culverts were built in lime-surkhi concrete, usually with faces and parapets of dressed stone, or precast cement-concrete blocks. Larger culverts of 10 feet span of this concrete were built on forms of "elephant shelters," familiar in France during the war. These corrugated steel forms were left in place to protect the concrete from boulders brought down by streams. They proved rather expensive, as they take up too much space in land and sea transport.

Digitized by Google


SECTION A A.
SECTIONAL ELEVATION X X. (REFLECTED)
PLAN.
Scale: 1 Inch = 20 Feet.
Scale: 1 Inch = 40 Feet.
Top of Wall Rise 2.7 Per Cent
Formation Level
Back of Wall
Front of Wall
Hard Shale
Lime Concrete
Cement Concrete
Coping Cement Concrete Block
Cement Concrete Top 10 Feet
Backing of Rough Dry Stone Wall 2 Feet Thick
Hearting of Lime Concrete with Plums
Ground Surface
Back Wall Rammer Directed 15 Feet on either side from Centre of Wall (Step № 10)
Bottom of Masonry
Bottom of Founds
Junction of Two Batters
Top of Wall
Centre Line of Wall
Ground Levels below Top of Wall at Back
Reactions:-
Foundations Lime Concrete with Plums 7½ Ballast & Bgrit to 2½ Mortar in proportion of 1 Lime to 2 Surkhi.
Cement Concrete 6½ Ballast to 4½ Cement & Bgrit in proportion of 1 : 3 : 6
Face Work & Hearting Dressed Stone Masonry in Class in Lime Mortar
Coping Cement Concrete 1 : 2 : 4 of 1 Inch Ballast.
Weep Holes about 8 Inch square provided every 5 Feet apart Vertically & Horizontally
Feet 10 5 0 10 20 30 40 50 Feet

Figs. 1.

Digitized by Google

They were used also for roofs of quarters in the fortified enclosures for the staff.

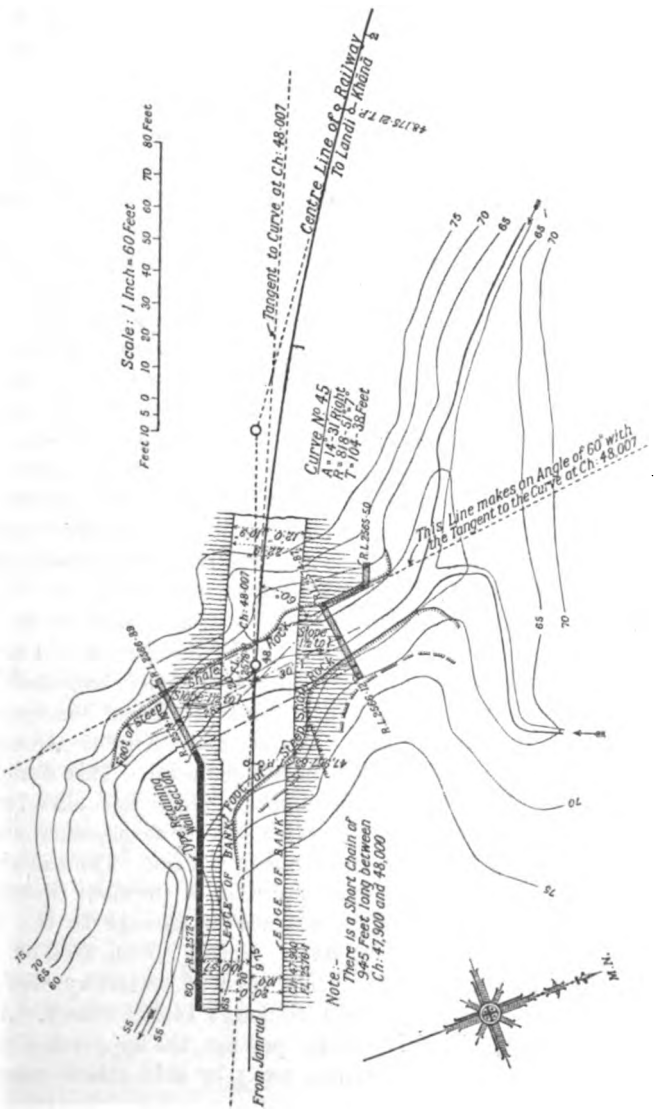

Scale: 1 Inch = 60 Feet
Feet 10 5 0 10 20 30 40 50 60 70 80 Feet
Tangent to Curve at Ch: 48.007
Centre Line of S. Railway
To Landi Kotal
Curve No 45
R = 1° 49' 31" Right
T = 104.38 Feet
This Line makes an Angle of 60° with the Tangent to the Curve at Ch: 48.007
Note:- There is a Short Chain of 945 Feet long between Ch: 47.900 and 48.000
From Jamrud
M.N.

Fig. 2.

The use of lime and surkhi for arched culverts may be questioned, but the calculated load was only 3½ tons per square foot. The

Digitized by Google

Author has since become aware of a failure of inferior lime-surkhi mortar by crushing at 15·4 tons per square foot, so the factor of safety is ample. An earth cushion of 2½ feet was provided.

Reinforced-concrete causeways were used near Landi Khana, and possibly these will be employed on frontier roads, as they are not liable to blocking, like the "Irish bridge" causeway, when the water subsides.

Fig. 2 shows the type of arch on the skew already described by the Author.[1] This construction avoided expensive skew-backs, and the doubt as to the effectiveness of a skew arch is provided against usually by a considerable additional thickness.

The finished area of tunnel-section was 428 square feet with curved side walls, and 441 square feet with straight side walls. It was regarded as important that there should be ample area on the severe gradients. Arch- or wall-thickness was usually 2 feet. The longest length of any one tunnel between faces or adits was only 1,403 feet, though further covering has lengthened one (driven with several adits) to 1,539 feet. The total length of all tunnels has become 15,327 feet, owing to the necessity of covering some of the cuttings. The total estimated cost of the tunnels was considerably exceeded, though a number were built at slightly over the estimated cost. The arguments for and against top or bottom headings were well exemplified, and neither proved quite successful.

The longest girder span is only 80 feet, in a viaduct, no other span exceeding 40 feet. In some of the bridges six old shallow girders were grouped, and reinforced concrete deck ballasted floors were provided. In a few short spans reinforced concrete deck ballasted girders were used. In the main Khyber stream the floor was put in at least 3 feet below bed-level. This design has proved efficient in two floods, one of which has already been referred to,[2] and the second of which (a very severe one) occurred on the 29th July, 1925, in the Khyber stream. The calculations were based on the arguments given in a previous Paper[3] by the Author, and the absolute absence of damage to the lowest bridge, which carried all the water flowing off an area of 42·12 square miles, is satisfactory. The area of waterway was 1,697 square feet, and the established discharge 14,500 cusecs. Appendix A gives particulars of various openings, the approaches to some of which were, however, washed away by side attack caused by short-circuiting of the stream.

[1] Minutes of Proceedings Inst. C.E., vol. ccxviii, p. 50.
[2] *Ibid.*, vol. ccxvii, p. 349.
[3] *Ibid.*, vol. ccxvii, p. 267.

Digitized by Google

The permanent way has 90-lb. flat-bottomed rails, principally on timber sleepers. Transition-curves of 105 feet only were introduced at the ends of curves of 818 feet radius. This may appear to be too short, but in practice the riding over them is excellent, the superelevation being run out at 1 inch in 30 feet. This means that when locating a series of reverse curves only 105 feet of tangent was allowed, an equivalent amount being taken from the offsetted curve. It is always economical to keep tangents between reverse curves as short as possible.

The line is a single one with ten crossing-stations (of which four are reversing-stations), so that the longest run is only 3·57 miles. The total length is 27·74 miles (of which only 26·35 miles have been laid). The capacity for daylight running is ample for many years, and, as conditions become stabilized, night running will more than double the capacity. It has been thought desirable to introduce "guard" sidings to prevent runaways, but modern automatic brakes render these practically a check on the driver's control of the train. To prevent runaways of vehicles in stations, "scissors" crossings are used at the "down" ends. Vertical curves are used at each end of the stations, and longer curves at the "guard" siding entrances.

The line was designed for 2–8–0 locomotives with 65 tons on the driving-wheels, one leading and the other pushing. Watering-stations are provided at Changai, Shahgai, Landi Kotal, and Landi Khana. The water for the first two comes from a spring in the Ali Masjid gorge, and practically all the water for the construction works in Division I came from this spring, being piped for a distance of nearly 4 miles. Break-pressure tanks were used, with automatic ball valves at every 500 feet of fall in level. Most of the other water came from existing piped supplies led from the Ali Masjid, Landi Kotal, or Landi Khana springs, though a few sporadic springs were discovered and utilized.

Massive defended forts were built at the stations, at a considerable cost. The use of pisé work in temporary staff-quarters was effective. The mixture was 7 shale, 3 clay, and 1 lime, and self-climbing shuttering was used in construction. Roofs were semi-circular, corrugated-sheeting backed, and plastered to a slope.

Execution of Work.

Other unusual features of interest were the provision of defended camps for the labour, and the maintenance by the political authorities of a considerable number of armed tribal guards posted

Digitized by Google

round camps, at tunnel-entrances, etc. Only one raid was ever made on a labour camp, with unimportant loss.

A very large amount of blasting was necessary, but few casualties occurred (thirty-five in 5 years from all causes), since strict rules were framed, and special blasting-supervisors were engaged for all high-explosive work. More than 100 tons of high explosive were expended, and the absence of accidents is gratifying, as is the manner in which the tribesmen tackled a work of which they have a right to be proud, and the manner in which they fulfilled their agreements.

Skilled labour had, of course, to be imported on to the work, and to reduce the quantity much use was made of plant, with good results. The Author spent nearly 6 months in England selecting this plant, and very few items did not do excellent service with increasing efficiency. A list is given in Appendix B.

The whole of the running and maintenance of the plant, including heavy repairs, was done by the engineers of the Indian Railway Service. A certain amount of subordinate European supervision was employed, but cholera and other disease gradually lessened this, and the Indians by that time had learnt to do without much supervision.

Perhaps the two most useful items of outdoor plant were the air-compressors (and drills) and the "Sentinel" wagons. The former got to work in the autumn of 1921, and by November, 1922, the headings of all the tunnels had been pierced, only a small proportion of which had been done by hand. By that time also the twenty steam wagons had reached a carrying capacity of 2,000 tons of material a month with practically no return load. Later, an even better results were achieved. Each vehicle ran up to 225 miles a month, while on the average fifteen were constantly on the road.

All the drivers and firemen were Indians, and only three vehicles met with crippling accident due to careless driving. The coal came from the Jherria field, the petrol (10,000 gallons per month) and explosives from Karachi. All stores had to be imported from long distances, necessitating great foresight.

Organization and Cost.

The Author, having derived useful information from similar reports, has added Appendix C to show the organization, and it may be noted that the large staff employed at the outset could be, and was, gradually and continuously reduced as the work settled down.

The cost will probably be close on £60,000 per mile, but the special circumstances have added at least 10 per cent. to the cost, swelled

Digitized by Google

as it is by the relatively high cost of labour and of supervising staff. The accounts system was organized with great care, but the latest details seen by the Author show that the allocation of the engineer does not appeal to the accountant. This is not new, but none the less very regrettable.

Having had to leave the Khyber Railway for other work in November, 1922, the Author feels that it is not out of place to record the determination with which the engineers pushed this work to a successful conclusion, their great patience, and the civilizing influence which they exerted.

The Paper is accompanied by nine diagrams and two photographs, from some of which the Figures in the text have been prepared, and by the following Appendixes.

Digitized by Google

APPENDIX A.

Khyber Valley Crossings.

Site.	Chainage or Work No.	Catchment Area.	Area Filled 1919.	Area Filled 1925.	Estd. Discharge. 1919.	Estd. Discharge. 1923.	Estd. Discharge. 1925.	Total Area Allowed.	Allowing half water below bed.
		sq. miles.	sq. feet.	sq. feet.	cusecs.	cusecs.	cusecs.	sq. feet.	sq. feet.
Seventh crossing, Charwazai . . .	(1,043)	..	..	904	..	..	..	904	664
Sixth crossing, Stupa	84,300 (1,026)	29·62	..	1,471	..	..	..	1,591	1,304
Fifth crossing, Zintara Bend. . . .	83,500 (1,023)	32·23	471	..	6,000	..	..	1,070	1,000
Causeway below Zintara	81,000	34·82	892	..	8,400				
Near Hazrat, Khan Kot	77,400	..	1,117	..	9,580				
Fourth crossing	(1,010)	36·74	..	..	..	..	..	1,110	
Causeway Dip, Kata Kushta. . . .	71,700	..	1,113	..	12,000[1]				
Third crossing	(1,007)	37·48	..	..	..	..	..	1,320	
Second crossing	(1,005)	37·83	..	..	..	..	..	1,439	
Below Kata Kushta	68,600	42·12	623	..	8,100				
First crossing	68,500	42·12	..	1,500	..	..	14,500	1,697	1,076
Causeway opp. 105	..	..	May '23 120	Aug. '23. 880	1,440	4,560			
Upper Bridge in Gorge	..	44·72	300	..	9,000[2]				
Malerkotla Bridge on Gorge	..	45·19	480						

[1] Not all water.

[2] At 30 feet per second.

Digitized by Google

APPENDIX B.

List of Plant.

Outdoor Plant.	No.	*Remarks.*
Air-compressors, portable No. 14		Insufficient number,
Imperial	24	Very good.
Leyner drill sharpeners	4	Saved tool steel.
Oil furnaces	3	,, ,,
Jack hammers	50	Very good.
Mountings and columns	6	Not necessary.
Air-compressor, 300 cubic feet, driven by oil engine	1	Rather weak.
Ball mill for surkhi	1	Very good.
Crane navvy No. 5 (Ruston)	2	Useful to supplement.
Equipment, drag line	1	Little used.
Concrete-mixers, 7 cubic feet, Ransome No. 0	4	Useful at large works.
Tonkin mixer	6	Very good.
Concrete tip carts, 6 cubic feet	12	Necessary.
Crusher, stone, 10 tons per hour	3	Stone flaked and was unsuitable.
Cement-tester, No. 3 Adie	1	Necessary.
Australian block-making machines	2	Useful.
Disintegrator	1	Too hard worked. Expensive in spares.
Portable steam-engines, 30 and 35 B.HP., single and compound	5	
Exploders, dynamo	20	Not used—electric detonators too expensive.
Locomotives, 2-foot gauge	2	Useful.
Self-climbing, steel shuttering		Very good.
Track, 20-lb. on steel sleepers, 7½ and 5 metres . miles	5	Insufficient.
Do., 14 lb., etc. ,,	2	,,
Turnouts	30	
Turn-tables	10	
Tip trucks, 1 cubic yard, side	60	
Tip trucks (with brakes), end	70	Insufficient.
,, ,, ,, side	60 30	
Wheelbarrows	1,000	Insufficient
Winch, steam	1	For incline.

The plant cost 10 per cent. per annum on capital cost in repairs.

Mechanical Transport.

	No.	
Sentinel 6-ton tipping wagons	15	Very good.
Sentinel 5-ton platform wagons, fitted gantries.	5	Very good.
Fiat 30-cwt. lorries	20	Indispensable.
Fiat 3½-ton lorries	5	Not a success.
Albion repair lorry	1	

Digitized by Google

Note.—The running cost of a steam-wagon, including depreciation, was 15 annas (pence) per ton-mile, against R. 1.5as. (21 pence) for carting. The road gradients were 1 in 13 (1 in 9 at one place), and the wagons had to go off the roads up ravines which were bad for tires. In addition to original covers and tubes 670 covers and 1,160 tubes were required for the 30-cwt. lorries, while 250 solid tires were required for Sentinel wagons in about 43 months. The life of back-wheel solid tires was 2,000 miles, and of front-wheel tires, 3,000 miles.

An allowance was made of 18 per cent. per annum on original capital cost for maintenance, and the Fiat 30-cwt. lorries cost this without tires. The Sentinel wagons cost 8½ per cent. per annum with tires.

The Sentinel wagons lifted 2,000 tons a month and did the work of at least 140 carts, besides handling material which no cart could have carried, such as 44-foot girders weighing up to 7 tons, rails 7½ metres long, tunnel timber, compressors complete, etc.

Two Fiat 30-cwt. lorries were fitted with rail wheels (and a turn-table), and were used as motor-trollies with great success for more than 2 years.

WORKSHOP PLANT.

	No.		No.
Lathes, 12½-inch	1	Shaper, 17-inch	1
,, 9½ ,,	1	Punch and shear	1
,, 6 ,,	1	Pipe-screwer up to 4-inch	1
,, 3½ ,,	1	Hacksaw, 5-inch	1
Drilling-machines, 20-inch by 1¼-inch.	1	Grindstone, 36-inch by 4-inch	1
Sensitive, ⅝-inch.	1	Blowers	2
		Automatic hammer, Blacker's	1

WOODWORKING.

	No.		No.
Roller-feed saw-bench, 38-inch	1	Thicknesser, 24-inch by 9-inch	1
Crosscut saw, 24-inch	1	Wall, boring, 12-inch by 2-inch	1
Ripsaw, 24-inch	1	Moulding, 14-inch	1
Mortising and chisel	1	Band saw, 28-inch	1

The whole was driven easily by a 70-HP. cold-starting crude-oil engine (in duplicate) with a consumption of 9 gallons per hour. This was far cheaper than a compound portable which was "pulled up" by the saw-bench alone. These oil-engines cost 9 per cent. per annum on capital cost to repair.

The machinery was accommodated in a shed 220 feet by 50 feet, and there was still room for a lorry workshop. Smith's hearths were accommodated in a lean-to. A marking-out floor was made in the open.

ELECTRICAL PLANT.

No.	Sets.	Driven by
2	10 kw.	20 B.HP. crude-oil engine.
2	5 kw.	10 B.HP. paraffin-engine.
4	2 kw.	4 B.HP. petrol-engine.
2	2 kw.	Coupled to 3 B.HP. petrol-engine, local supply.
1	1.6 kw.	(Ferro printing.)

Digitized by Google

The first two were not used, as power could be obtained from military plants. Two of the belt-driven 2-kw. sets were used in tunnels.

The whole of the above (except the Sentinel wagons and Ruston excavators, for which experts were brought out from England) were erected by the staff. The drivers and workmen were hard to get and to keep, since the frontier attracts few who can get steady employment elsewhere. But, on the whole, the plant was worked with good efficiency. The portable compressors, for instance, which started by consuming 2 gallons per hour each, came down to 1½ and even 1¼ gallon of petrol per hour.

APPENDIX C.

Organization.

The special circumstances at the commencement made it necessary to have a strong staff and some reserve.

The Author was Engineer-in-Chief, and the work was divided between :—

Personal assistant	
Estimating and design . .	One executive and one assistant.
Works, Division I (Jamrud exclusive to Kata Kushta) 13 miles	One executive and three assistants.
Works, Division II (Kata Kushta to Landi Khana) 14 miles .	One executive and three assistants.
Mechanical Division (including railhead buildings, etc.) .	One executive and one assistant, one mechanical engineer, one transport officer.
Stores	One controller.

Divisions I and II had 1 mile taken off and added respectively so as to bring the Ali Masjid gorge into Division II, owing to want of progress in Division I and the fact that several miles in Zakka Khel territory were not taken up owing to non-submission.

There was a special audit officer. The medical arrangements were under the agency surgeon, Khyber, with three sub-assistant surgeons, three compounders, and two sanitary sections (later reduced to one).

By November, 1922, the executive and assistant on estimating and design, one assistant in Division II and one in the Mechanical Division had been dispensed with. The Mechanical and Stores Divisions had also been amalgamated.

In October, 1923, both Works Divisions were amalgamated, with four assistants only, and in February, 1924, the Executive Engineer of this

Digitized by Google

Division became Superintendent of Works of the whole construction, with two assistants only from April, 1925, onwards to date of opening.

The outdoor subordinates in both divisions numbered twenty-one at the start, and reduction was more gradual.

The clerical staff in the Engineer-in-Chief's office numbered twelve, with nine in each of the Works Divisions. The drawing was principally concentrated in the head office with four draughtsmen, four tracers and one ferro-typer (also photographer), but each Works Division had one draughtsman and two tracers for detail drawings.

The Mechanical Division had four clerks and one draughtsman. The Stores Division had four clerks with seven sub-storekeepers and store clerks at Jamrud and Landi Kotal.

The Audit Office had one accountant, four superintendents, twenty-four clerks and a cashier.

The total cost of establishment was about 9 per cent. of the total cost, and this included leave allowances of permanent officers (who, in some cases, earned their leave on other railways). Most of the office accommodation and temporary quarters had to be built at the high rates prevailing in the Khyber.

Stores Division.

This dealt with stores to a total value of 85 lakhs of rupees (£566,600). The principal items are valued at :—

Permanent way	Rs. 19,58,000
High explosive (100 tons)	4,03,000
Fuse (183,642 coils) and Detonators (684,845)	1,25,000
Petrol	4,40,000
Oils	1,70,000
Tires and tubes	1,51,160
Coal	6,00,000
Cement	6,12,000

The plant cost about 35 lakhs of rupees.

The Division was responsible for all material and ballast-train working, and a special word may be said for Sub-storekeeper Pandit Manohar Lal, through whose hands at Jamrud all this material passed.

Digitized by Google

Discussion.

Mr. W. W. GRIERSON remarked that the British engineer who, like himself, had no personal knowledge of conditions in India would probably consider that the most informing part of the Papers was contained in the particulars given as to the ruling gradient and minimum radius of curves adopted for a broad-gauge railway in a mountainous country. He was extremely interested in the descriptions of the country, of the savage tribes residing there and the consequent delicate negotiations which had to be carried through, and of the arrangements which had to be made with the tribes to enable construction to be carried on. The Papers would be particularly instructive to engineers who might meet with similar unconventional conditions, where a considerable measure of tact, patience, and judgment was almost as necessary as technical knowledge. The ruling gradient from Jamrud to the summit was substantially 1 in 33, which in this country would not be considered for a first-class or second-class railway, or even for an unimportant branch line if it could possibly be avoided. The natural features of the country had, however, to be faced, and he thought the engineers had done well in getting a gradient even as good as 1 in 33, and in all probability it would, he thought, prove quite satisfactory under the circumstances. A modern eight-coupled engine would haul up a 1-in-33 gradient about 150 tons—fifteen 10-ton wagons—or even more where the curves were not very severe, and seeing it was contemplated that two locomotives would be used if necessary, the load could be doubled. As an instance of what could be done he cited the Lickey incline of 1 in 37 on the main line, between Gloucester and Birmingham, on the former Midland Railway; the incline was 2 miles long, and heavy traffic had passed over it for many years. On the main line to Plymouth, also, there were several gradients of about 1 in 40. He was not holding up those instances as examples to be followed: they were very objectionable; they limited the load and reduced the speed, and the working-expenses were heavy; but they indicated what could be done when there was no other alternative. From the summit of the Khyber railway down to the Afghan frontier the gradient was 1 in 25. Colonel Hearn stated that a very distinguished Royal Engineer, Lord Kitchener, thought a railway would be impossible, and therefore the engineers might congratulate Mr. Grierson.

Digitized by Google

Mr. Grierson. themselves that they had done well. The minimum radius of curve was 818 feet, practically 12½ chains; that was a very good curve for mountainous country, and was very much better than curves existing on many lines in this country over which heavy coal traffic was carried and numerous passenger-trains ran. The Board of Trade required a check rail to be used when a curve was of a radius of 10 chains or less; and if there was a similar provision in the Indian requirements, the limiting curve for a 5-foot 6-inch track would be somewhat greater. It would be interesting to know whether an 800-foot curve would escape the requirement; because, if so, a very considerable sum would be saved on a railway 50 per cent. of which consisted of curves. Consideration had been given to the question of adopting a narrower gauge for the Khyber railway, and a gauge as narrow as 2 feet 6 inches had been proposed and rejected. He thought that was a wise decision, but not altogether for reasons which Colonel Hearn gave. It occurred to him that a break of gauge at Jamrud, especially in the case of a railway which was largely constructed for military purposes, would be extremely objectionable, and further, the volume of traffic that could be carried on a metre-gauge line would have been considerably less. One reason given by Colonel Hearn was that he found he could accomplish with an 800-foot curve all that could be managed with a much sharper curve such as would have been permissible with a narrower gauge, and though this was not usual, he accepted, of course, what Colonel Hearn said. He did not, however, think the further reason given by Colonel Hearn, namely, that the cost of tunnels was not in proportion to the sectional area, was equally forcible, because the cost of earthwork, bridges, and tunnels on a metre-gauge railway would undoubtedly have been much less than on the broad gauge. It seemed to him, therefore, that, if the two considerations he had mentioned, namely, the break of gauge and the reduction in volume of load carried, did not apply, evidently the proper thing to have done was to adopt a narrower gauge, thereby greatly reducing the cost. It was possible that in time the railway might be extended, and that for reasons of economy a narrower gauge would become essential, but he took it the Indian Government would very much prefer that any break which occurred should not be on British territory. Mr. Bayley referred to the merits of top and bottom headings in tunnel construction and to the great differences of opinion which existed. There were cases where the strata or the presence of water might determine that the heading should be at the top or at the bottom, but he suggested that, generally speaking, the question was very similar

Digitized by Google

to the question whether fir sleepers should be placed with their sawn side upwards or downwards. That question had had very careful consideration recently, and it had been found that the opinion of engineers was almost equally divided, and that the average life of a sleeper was about the same whether the sawn side of the sleeper was above or below. Probably the tunnelling contractor would be most successful with the methods with which he was most familiar. He noticed that the tunnels on curves were built to wider dimensions, for the purpose of enabling the full load-gauge to pass through, and he took it that that was now common practice, although it had not always been so, and the result had been great inconvenience and cost. When the Berne gauge on the Continent was first brought to the notice of a committee of which he was a member, it was generally thought that the full load shown by the diagram would pass throughout over the international railways on the Continent. That, however, was not so; it merely meant that the full load could be accommodated on a straight line, and a reduction had to be made for the curves and also for constructional encroachments. In this country a great deal had been done by putting back platforms on curves and by widening bridges as reconstruction became due, but the cost of altering tunnels was practically prohibitive. Mr. Bayley raised the question whether horizontal stress would be imposed on intermediate bridge-piers due to braking loads on a steep gradient. Possibly it would, but he was rather inclined to think—and he was not quite sure that Mr. Bayley did not agree to some extent—that a good deal of stress would be eliminated by the resistance of the permanent way. Rail-creep had caused many railways a great deal of trouble and expense, but with the modern chaired road there was very little trouble—in fact, it had been practically eliminated. He suggested that, if the piers should show any indication of stress, the question of taking up the flat-bottomed road for some little distance on each side of the bridge and over it, and substituting a chaired road, might be worth consideration. He had not had experience of any bridges with such a steep gradient as 1 in 33, but in Devonshire and Cornwall there were numerous viaducts, the piers of which were well over 100 feet in height, with gradients of 1 in 70 or thereabouts, and so far as he knew they had never given any trouble or shown any signs of stress. The question was interesting, and he agreed with Mr. Bayley that it might form the subject of experimental observation. In conclusion, he thanked the Authors for their interesting Papers. Great credit was due to them and also to the Political Officer for the success with which they had carried out the work

Mr. Grierson.

Digitized by Google

Mr. Grierson. and for the arrangements they had been able to make, without which the construction of the railway might not have been possible.

Brigadier-General Guy Lubbock. Brigadier-General Guy Lubbock, C.M.G., D.S.O., late R.E., remarked that he had listened to the Papers with great interest and with, perhaps, a tinge of envy, because he was the engineer who built the previous railway, which had to be abandoned. He could endorse all that Mr. Bayley had said about the labour difficulties. Looking back, it seemed to him that 90 per cent. of his own difficulties had been labour and the management of labour, and 10 per cent. technical. His staff were not quite so experienced—and he certainly had not had very much experience—in dealing with the Khyber tribes at the time. He could well remember that injudicious allotments of contracts for which a man would not expect to get more than £100 quite often led to bloodshed; in fact, one discontented tribesman took to shooting at him one day!

Dr. Lowe-Brown. Dr. W. L. Lowe-Brown congratulated the Authors on having been able to build a first-class railway under such extraordinarily difficult conditions. There seemed to be substantial reasons that were not given in either of the Papers for adopting a 5-foot 6-inch gauge. The very nature of the construction showed that it was not looked on as a branch railway for light traffic, but that it was of importance either as a strategic line or as a link in a future trunk line; and consequently the policy of avoiding a break in gauge was the only one possible under the circumstances. There was one remark in Colonel Hearn's Paper which he thought ought not to be allowed to pass unchallenged, and that was the statement that: "However sharp may be the curves for which a locomotive is designed, there is a practical limit, which the Author believes to be 800 feet for an eight-coupled locomotive, whatever the gauge may be." He was surprised that Colonel Hearn should make such a statement when there were numerous examples of 3-foot 6-inch and metre-gauge railways with curves of 400 feet radius, and less, working quite successfully with the heaviest locomotives. For a 5-foot 6-inch gauge railway, of course, 800 feet was about the minimum radius that could be worked with comfort. Considering the amount of development that had had to be done to get them, the gradients, though steep, were probably the best obtainable at anything like economic limits. With regard to the survey, he wondered if the use of stereoscopic photography for the reconnaissance and preliminary survey had been considered, because he would think that the conditions were almost ideal for this method, which would have minimized the time spent in the field—an important consideration under hostile conditions. Colonel Hearn

Digitized by Google

Dr. Lowe-Brown.

referred to taking advantage of the dip in the strata to reduce the cost of earthwork in the cuttings; this was very interesting, but there must have been considerably more continuity in the geological formation than was usually the case, to make one side of the valley so continuously favourable as it apparently was in this instance. The use of zig-zag or reversing stations, especially when they were in pairs with a relatively short length of line between, was often necessary for a line of relatively light traffic, and in some places they were used with very heavy traffic; but they were always objectionable, and it showed a proper appreciation of future development to have kept in mind the possibilities of being able to eliminate these reversing-stations in the future, when the volume of traffic warranted the expenditure. Indian railways were fortunate in having such a very large construction gauge, which was large even for a 5-foot 6-inch track; but in designing the tunnels a very generous additional allowance had been made on the curves, and it was instructive to compare these tunnels with an Argentine tunnel for a 5-foot 6-inch gauge with the same curvature, that he had previously described,[1] which was of oval section 16 feet 10 inches wide and 17 feet high. The Khyber tunnels were 21 feet 6 inches wide and 22 feet 1 inch high, that was, almost 5 feet larger each way than those in the Argentine. There was a remarkable similarity in the cross sections of the two examples, so there was no need to make allowances for difference in form. The only real difference was that in the Argentine tunnels the whole cross section was superelevated on the curves to follow the track. The bridges were designed for 24-ton axle-loads. He did not think that was too much, because, if the railway ever became a link in a big trunk line, it might be worked by very heavy engines. The North-Western Railway (India) had already 20-ton axle-loads on some mountain railways, and even heavier loads might be used in the future. The track of the Khyber railway had thirteen sleepers to a 39-foot, 90-lb. rail. If the railway ever carried traffic sufficient to justify the expense already incurred, he thought the track would be found too light and more sleepers would have to be put in, or heavier rails, or both, before the rails were worn out. The transition-curves of 105 feet were undoubtedly short, the object having been to cut down the length of tangent between the two curves in the case of reversed curves. As the speeds were comparatively low, it would be possible to work out the superelevation at the rate of 1 inch in 30 feet in a curve of that length, and since, according

[1] Minutes of Proceedings Inst. C.E., vol. ccv (1917), p. 165.

Digitized by Google

Dr. Lowe-Brown. to the Paper, the traffic was worked over that section without discomfort, the short curve might be considered justified.

Mr. Beaumont. Mr. E. G. E. BEAUMONT remarked that in the construction work an interesting application of road transport to a remote area had been made. It was further noteworthy by reason of the successful working of heavy steam vehicles under conditions which usually necessitated the employment of the petrol vehicle. The conditions of working had been extremely severe, and the monthly mileages had been of the order of 425 for the light vehicles and 225 for the steam vehicles. Those rates of working were uneconomically low, and yet, despite that, the cost per ton-mile and per mile run was on the whole better than was achieved in this country for such a low rate of working. That was to be explained, perhaps, primarily by the fact that the labour costs were so low. The labour item was usually a preponderating one, even in the work of motor-vehicles. Between Colonel Hearn's figures and Mr. Bayley's figures there appeared to be a discrepancy which it might be worth while to clear up. Colonel Hearn described the working rate of a steam vehicle (p. 40) as 225 miles per vehicle per month, but apparently Mr. Bayley gave the rate as 425 miles per month (p. 19) and the connection between the mileage run and the ton-mileage worked agreed in the two cases. If Mr. Bayley's figures were correct, it would seem that the cost should be nearer 10 annas than 15 annas per ton-mile. It would be useful to know what the coal had cost delivered on the works, and what kind of coal had been used, especially as the consumption was high, namely, 40 lbs. per mile worked. Further, at what cost had the petrol been obtainable? Another interesting point in the use of road transport was the fact that all the vehicles were by well-known makers. In the case of the Italian Fiat vehicles one type succeeded and the other failed. It was always possible to profit by the lesson of failure, and it would be interesting to have a clearer explanation why the 3½-ton Fiat lorries failed. They were chain-driven vehicles, made in a country where mountain roads abounded, and they were undoubtedly of high-class workmanship. It rather suggested that their failure in this instance might be attributable to some special circumstances in their application. They were fitted with a governed engine, and if the governors were not used, the lorries would be exposed to the effects of unduly fast running. Had it been found difficult to keep the governors in action when the vehicles were in use? Undoubtedly labour conditions multiplied the difficulties and might explain the failure of that type of vehicle. It might be, also, that the size was unsuitable for carrying railway

Digitized by Google

material, and occasionally unavoidable but serious overloading occurred. With regard to the electric plant, had direct- or alternating-current generators been employed, what voltage had been found to be suitable, and what kind of distributing conductors had been used, particularly for tunnel lighting ? Mr. Beaumont.

Mr. BAYLEY, in reply, thanked the members for their indulgent reception of his Paper. The curvature of 7 degrees, or approximately 12½ chains radius, had been found to fit the Kyber hills admirably. No check-rails were required. Running was smooth with the superelevation and short transition-curves adopted. He was surprised at the references to the possibility, under certain circumstances, of a break of gauge being used. In his opinion a break of gauge was a mistake. The Khyber railway had been built to the new Indian construction gauge, which was very much bigger than the old. As soon as these larger dimensions came into general use, very much larger rolling stock would become possible on the 5-foot 6-inch gauge. Indian standard dimensions required considerable additions to widths on curves, varying with the degrees of curvature. These considerations accounted for the large size of the Khyber railway tunnels. He noted with much interest Mr. Grierson's views on braking stress and rail-creep on high bridges, and it was reassuring to learn that no consequent trouble had come to light. The suggested use of a section of chaired road in the neighbourhood of a high bridge was useful. In reply to Mr. Beaumont he regretted that he was unable to supplement his account of the failure of the 3½-ton lorries under the severe conditions in the Khyber Pass, nor had he the figures of the cost of coal and petrol in his possession. The apparent discrepancy between Colonel Hearn's and his own figures of average monthly mileage for the steam lorries was probably due to the average being taken over different periods. There was a marked peak in the curve of monthly mileage for a short time, and his figures related only to this peak, when the lorries were at their busiest. Mr. Bayley.

*** Colonel Hearn's reply will be found at the end of the Correspondence (p. 75).

Digitized by Google

Correspondence.

Major Anderson.

Major E. P. ANDERSON, R.E., observed that the excellence of the work of Colonel Hearn and his surveyors was well indicated by the fact that only one serious change in alignment had been found necessary during construction. This was the curve at the head of the Changai nullah (p. 30). The original alignment involved making a length of line near the waterfall with formation partly in bank, supported by two large retaining-walls. At the site proposed for one of these he measured a side slope of about 60 degrees, and found that the dimensions of the wall to secure an adequate foundation would be impracticable. He therefore arranged, with Colonel Hearn's concurrence, to realign this portion, throwing the centre line 12 feet farther into the hillside and thereby making the whole width of the formation in cutting. This apparently small change involved the realignment of a compound curve 1,500 or 2,000 feet long; it eliminated the two walls, but changed a deep cutting into what was now Waterfall tunnel (Fig. 7, Plate 1). This tunnel passed under an apparenty dry stream-bed, from which there was a good deal of leakage of water into it during construction. Later another deep cutting on this realignment was changed to the cut and cover now known as Changai IV. The result was a safer, though slightly more expensive alignment. Mr. Bayley's Paper rightly emphasized the unusual "political" conditions under which the work had been carried out. The engineers' anxieties on this account had been often greater than upon any other, and while it might be thought invidious to mention by name in this connection anyone still living, he would like specially to put on record the debt of gratitude due by the engineers of No. 1 Division to the late Major H. Finnis, of the Indian Political Department, for his invaluable assistance at a very critical period, particularly in the Kuki Khel area. The relative merits of top and bottom headings in tunnels could never be finally settled; but, if he had to start work again in ground similar to that experienced in No. 1 Division, he would always begin with a bottom heading, but change to a top heading immediately any bad or even doubtful ground was encountered. The Indian Railway Bridge Rules dealt very fully with all sorts of steel girders and arches, but left the design of piers entirely open to the engineer. As they contemplated stresses due to braking and traction in the steelwork, it would at first sight seem that such stresses must be transferred to the piers. But an

Digitized by Google

examination of a number of old but similar bridges on heavy gradients on the Quetta division of the North-Western Railway disclosed no sign of this being the case, and it would therefore seem more reasonable to suppose that such stresses were, at any rate, on the moderate spans used on the Khyber Railway, entirely taken up by the track, which was well anchored in good ballast. This seemed to be corroborated by the fact that breakage of fish-bolts near bridges by shearing under ordinary traffic was to all intents and purposes unknown on the Quetta division, and he had not heard of any on the Khyber Railway up to the time when he left that part of India. The high cost of cement had made it desirable to carry out as full experiments as possible on locally-produced lime and surkhi. Perhaps the most interesting result of these was that the addition of 10 per cent. of Portland cement to the 1 : 2 lime-surkhi mixture used on No. 1 Division doubled the tensile strength and halved the setting-time of the mortar. Major Anderson.

Mr. T. J. BOURNE considered the Papers to be of exceptional interest to railway-engineers who might be called upon to carry out works in similarly wild country—wild as to both terrain and inhabitants. It was regrettable that plans and sections to larger scales could not be given, as the survey and location were of great importance and interest; and the part which a geological study of the possible routes had taken in the final location was a useful reminder to those engaged in similar problems elsewhere. Mr. Bourne.

A more detailed description of the "work-numbers" system would be of great interest. In a recent experience of Mr. Bourne's this method—derived in that instance from mining practice—seemed likely to run into thousands of work-numbers for each small section of line, and the method referred to by Colonel Hearn must have been very different. In what way was this method preferable to the "classification of railway estimates" with their careful definitions, drawn up by the Government of India and adopted in other countries with much success? Colonel Hearn's statement that the engineer's allocation did not appeal to the accountant recalled the rarity of, and the extreme difficulty of keeping, correct and at the same time useful costs and accounts for a railway during construction. The only possible method seemed to be for the engineers to keep the detailed cost accounts and the accountant to keep only the main heads and subheads of expenditure. The engineers must then have their own cost accountants and clerks, and these costs must be correlated to sum up correctly with the accountant's headings. Unless this balance was maintained, the engineers' costs were inaccurate and deceptive, and could not be

Digitized by Google

Mr. Bourne. monied out to the total cost of the railway. The expense of such cost clerks was rarely conceded to construction engineers; and even if strictly correct costs were kept, their application to other railways, would be still very difficult. Each cost account would have to be accompanied by a long description of all the conditions under which the price was made. The method which Mr. Bourne found most convenient for storing and filing the plans of a railway was the Continental one of making the blue prints into folders of reasonable length, folded like the sides of a concertina or a Chinese picture-book. Each folder was then endorsed and laid horizontally among its own group in a numbered pigeon-hole. It could be opened to show as much or as little of the line as was required to be studied, and continual rolling and re-rolling was avoided. Moreover, such folded plans could be examined at an office desk while writing a letter or making calculations. Whenever an alteration was made on any drawing, the date of revision was marked clearly on the tracing and so came out on every print issued.

Information as to the calculated allowances for settlement, the actual observed settlement, and the time settlement had continued on the very high banks would be of interest. For basket-filled earth in China he always used a settlement table which allowed a sliding scale for the top 2 feet of bank plus a straight percentage settlement varying with the material, for the remainder. Some information as to the methods used in moving cut to fill would be interesting. It would appear that the greater portion of the work had been done with hand-pushed side-tip wagons. How had the track been supported for the side-tip wagons? The building of arch-rings in lime-surkhi—the wisdom of which Colonel Hearn questioned—would appear to be a rash experiment. Railway arch-rings in the very soundest materials were prone enough to give trouble. That the cost of a railway presenting so many problems which could only be solved after actual experience of the work should come within 10 per cent. of the estimate appeared, in view of numerous experiences elsewhere, to be very creditable to the estimators.

The difficulties, on the human side, of working in the tribal zone must have been immense. Construction engineers generally expected to select and appoint their own contractors and men; and the necessity of using men selected by a non-technical outside department, and of making good with them, must have called for great tact and patience. In early pioneer work in China the experience was that, though labour was always plentiful, the local labour on each new railway taken up was untrained and condemned by everyone as "bad." But, after 3 years on one zone, the "good"

Digitized by Google

men for work on the next section of country dealt with were the " bad " men of the last, who by then had been trained, had grasped the foreign ideas of railway work, and had acquired confidence in the foreign civil engineer. With regard to the tunnels, was it not very expensive and slow work to push tip-wagons by hand up gradients, and would it not have proved more economical to use 2-foot-gauge petrol locomotives, at least for the upgrade ends? It would be useful for future cases to know the total or percentage cost of motor and other transport services for men and materials. The adequacy of the flood-openings, as tested by a maximum flood, showed the value of the formula used. In North China Mr. C. W. Kinder, C.M.G., M. Inst. C.E., established by experiment, after a great flood, a coefficient of 10 in Colonel Dickens's formula, and Mr. Bourne always used this with good results for openings determined by catchment-area. Actual data of rainfall over periods ranging from ½ hour to 3 days, in mid-China, pointed to the following probable maximum falls in those latitudes :— Mr. Bourne.

Duration of rain : hours	½	1	4	12	24
Maximum fall : inches	2	4	8	12	16

In Hongkong (South China), 24 inches fell in 24 hours in May, 1889.

He always designed piers (generally of moderate heights and spans) for a braking stress of one-fifth of the weight of the engine on the span, and brought the resultant down within the middle third. He did not know whether any records existed of piers actually failing under this stress; but the stress must be there, and as to relying on the continuity of the track, it seemed clear that in the case of heavy creep down-grade, assisted by high sun temperature, the track might assist the braking force to overturn the piers in the down-grade direction rather than prevent it from doing so. The method adopted on the Khyber Railway seemed practical and adequate, though, as pointed out, it would be expensive, and at times difficult, to build a high abutment of sufficient strength to resist the stress.

Mr. W. M. BURTON remarked that it would be useful to know what the organization of the survey parties had been, and what personnel had been European and what Indian. Perhaps it was the presence of Indian assistants that had led to the use of the plane table for contouring, for it was not clear that it had any advantage over a tacheometer for that purpose. He gathered, however, that the tacheometer had been somewhat reluctantly used, only where other methods were impossible; and this was the attitude that he had found his Indian-trained colleagues in Mesopotamia took up. For instance, Colonel Hearn allowed (p. 29) that work done by Mr. Burton.

Digitized by Google

Mr. Burton. tacheometer was satisfactory, but he spoke in the same sentence of "more serious work." Those who had used tacheometers for years, in all sorts of country and under all sorts of conditions, would not attempt to do difficult survey work by any other method; and predicted sections could be more accurately arrived at by its means than by others—partly, he thought, because other methods became so tedious to Europeans that they were apt to scamp the cross-sectioning work. The previous levelling and check-levelling of the tacheometer stations rather pointed to distrust of that instrument, for it was quite unnecessary. On a location in the Andes, after 60 kilometres of the severest work, the final levelled section had proved the tacheometer section to be within 60 centimetres, a smaller difference than a leveller and check-leveller working independently would expect to obtain in that distance. He agreed that reductions of readings to two decimal places were quite unnecessary, and that diagrams were preferable in certain circumstances; if, however, Jordan's tables were used, the reduction could be done very quickly by two juniors working together. He agreed that, within reason, easy curves should be adhered to, even at the expense of rather heavier work, for, on a steeply falling line, an appreciable amount of height could be lost through compensation. Colonel Hearn did not state what rate of compensation he had used in the curves; it would be very interesting also to learn whether there was any stalling upon the curves, for there were not many railways in operation with such lengths of continuous steep gradient, and the formulas were somewhat empirical. He presumed that the reason why the reversing-stations had not been made on momentum gradients was that they were required for the purposes of passing-stations as well. He congratulated the Authors upon the fact that the line was in operation: so many engineers had to be content with locating railways which they never saw in operation, and they were, therefore, unable to correct their theories.

Mr. Johnson. Mr. F. R. JOHNSON observed that, as he understood, the reconnaissance and preliminary surveys occupied 4 months for 40 miles, two field-parties being employed; and that period did not include a staked-out location. The construction length, however, appeared to have been only 27¾ miles. While he did use barometers for important points, such as the relative elevations of passes in a range of hills, etc., he considered that the usefulness of that instrument ended there, and that little or no detail could be got by its means without much waste of time that would be better occupied in angular levelling. Under these circumstances he failed to understand Colonel Hearn's predilection for this instrument out of its usual sphere,

Digitized by Google

and he would have liked to see some of the preliminary sections obtained with it, and some details of the time required. So far as his experience went, quicker and more accurate results would be obtained by angular levels, coupled with chained distances, as carried out by him on the reconnaissance of the Laling Range in the Deccan[1], where the error over 5¼ miles of rocky ground, including a rise of 34 feet to the summit, and a fall of 196 feet beyond, was only 1·39 feet, as afterwards found by spirit-levelling when the line was located. That preliminary work occupied only 2 days, and provided a plan, section, and cross sections on which the proposed location was laid down without difficulty and immediately staked out. Again, on the Bear Creek Hydrographic Survey in British Columbia[2] the stadia system was used with angular levels to "height of instrument" and on a 24-mile closed traverse the level error was found to be only + or — 4 feet, and this over mountainous ground, where the main survey, starting at 1,135 feet above sea-level, ended at 4,870 feet amidst heavy snow in August. Mr. Johnson, being familiar with the Rocky Mountains—not to speak of the Selkirks and the Gold Range, which intervened between them and the Pacific Coast—and having worked for 9 years amongst the mountains of the interior, as a British Columbia Land Surveyor, frequently under arduous conditions of below-zero weather, snow, and very heavy timber, both standing and fallen, was under no delusions as to the nature of the ground and the difficulties which Colonel Hearn had had to traverse and contend with in the Khyber Pass, although he had not himself been so far north in India. He was of opinion, however, that, practically, both reconnaissance and preliminary survey in one could have been done much more quickly and effectively by either of the systems above mentioned, or perhaps better still by the one used by him on the reconnaissance surveys for proposed feeder railways in the United Provinces, Bundelkhand, and Central Provinces (season 1922), where a complete plan and a section for about 92½ miles (more than 100 miles including rejected lines) were obtained in 3½ months in the hot season (mid-February to the end of May) without other professional assistance than a native surveyor to work the plane-table for topographical details. The scales to which the work was afterwards plotted were 800 feet to the inch horizontal (6·6 inches to the mile) and 80 feet to the inch vertical, on 4-mile sheets.

Mr. Johnson.

[1] "The Survey of the Manmad-Dhulia Railway, India." Minutes of Proceedings Inst. C.E., vol. cxv (1894), p. 343.

[2] Minutes of Proceedings Inst. C.E., vol. clxxxviii (1912), p. 371.

Digitized by Google

Mr. Johnson. Practically all banks and cuttings of any importance were shown, and the bridging was detailed, so that, although scheduled as a reconnaissance, to all intents and purposes it formed both that and a preliminary survey, accompanied by earthwork and masonry quantities, etc., and an estimate. The first portion, Harpalpur to Mhow (beyond Nowgong), about 22 miles, was done with the tacheometer, and completed about the end of March, when it became imperative to make more progress, so as to finish the surveys before the monsoon set in. The method then adopted was the tangential system for distance, taking vertical angles to (generally) a 10-foot base on a levelling-staff held vertical, and occasionally angles to a longer horizontal base marked by ranging rods, with vertical angle levels in both cases. For distance by this method a table was provided by the Royal Geographical Society.[1] During April the average progress was 2 miles per day, with a maximum of 4½ miles, including numbered stakes placed at all instrument and staff traverse stations, small pits dug on either side of them, and intermediate sights to nullahs, or varying ground, taken as required. The system of carrying on the survey which made the above progress possible was a modification of that initiated by Porro[2], in that only every other station was occupied by the instrument, and all horizontal angle readings were taken on the compass, while vertical angles for distances and levels were read on the vernier of the vertical circle to 30 seconds. As a result of the great advantage of having only to occupy every other station, and the still greater advantage of not having to centre the instrument over the stake—because wherever it was driven (namely, under the plumb-bob or under the staff) was the correct station-point—the progress was about trebled. Had Moinot's system been adopted, it would have been necessary to occupy every station consecutively, and centre the instrument over every peg. The district covered by this survey was, of course, not mountainous in the proper sense of that word, although on the feeder lines in question there were about 10 miles of 1-per-cent. gradient and a good deal of rough rocky ground; but the methods outlined were particularly adapted to mountain work in such localities as the Rockies or the Khyber Pass. He failed to understand the object of levelling and check levelling all stations to be occupied by the tacheometer before its use on the preliminary survey. In his experience angular levels were

[1] "Hints to Travellers," 9th ed., vol. i, p. 343. London, 1906.

[2] See B. H. Brough, "Tacheometry, or Rapid Surveying." Minutes of Proceedings Inst. C.E., vol. xci (1887), p. 282.

Digitized by Google

amply sufficient for any work of this nature on mountainous ground, where petty detail was quite out of place, and it seemed that this was getting even nearer to a pin-point than the calculation of tacheometer sights to two place of decimals, rightly avoided by Colonel Hearn. When once the route had been found, the sphere of usefulness of the tacheometer, as a rule, ended, in the same way as that of the barometer when the lowest summits had been obtained, so that 2 or 3 feet for the first and 10 or more for the latter instrument were of no consequence; hence checked spirit-levelled heights for instrument stations appeared to be redundant. He had once come out with a barometer level of 2,980 feet above sea in the mountains of British Columbia, as compared with 2,982·7 feet obtained by the stadia, but he was inclined to look on that as in the nature of a miracle. However, the air of the Khyber might possibly be better suited to the barometer's somewhat delicate constitution and variability. There were very useful tables[1] for the system of chaining combined with angular levels to height of instrument, from which the rise or fall and horizontal distance could be quickly obtained to any desired degree of accuracy; and in England this system had been used to such good purpose that it eliminated a proposed tunnel 1½ mile in length with long and heavy bank approaches 80 to 90 feet deep, and substituted only ¼ mile of tunnel, with works of quite an ordinary character. Mr. Johnson.

Mr. W. O. Leitch remarked that the bridge-pier foundations were apparently about 12 feet, and the floor about 6 feet, below the dry river-bed. What was the depth of the curtain walls, what did the material of the river-beds consist of, and why had floors been adopted instead of sinking wells? Even if the bridge extended from side to side of the nullah, the piers caused some obstruction, the channel was reduced and the flood-level raised, and scour was increased after the building of the bridge. Curtain walls might be damaged or underscoured in the course of time, so deeper piers, without floors or curtain walls, offered an interesting alternative. Although the flood mentioned by Mr. Bayley occurred at night, others might have happened since. Had any banking up of the water above the bridges occurred? Perhaps Colonel Hearn would say something about the effect of restricting channels. When the quantity of flood-water to be taken into account had been fixed, there still remained a problem about which not much had been written, namely, how much would the previous flood-levels be raised, how much would the flood bank Mr. Leitch

[1] W. D. Haskoll, "The Engineer's, Mining Surveyor's and Contractor's Field-Book." London, 1880.

Digitized by Google

Mr. Leitch. up, and what would be the new gradient and discharge through the bridge. Most flood-openings restricted the old channel more or less, with important results to bridge protection-works.

With regard to the girders on the 4-per-cent. gradient, had the wooden blocks shown any signs of crushing? Thirteen sleepers to a 36-foot rail was much less than American practice. What axle-load was allowed, and what were the rules as to axle-loads and sleeper-spacing? Was the rolling stock entirely fitted with power brakes for controlling the down-hill speed? Although it partly depended on the quality of the coal and the experience of the drivers, it would be interesting to know the train-load actually handled on the worst gradient, and also the type of locomotive.

Mr. Leitch had been connected with a tunnel in North China 4,000 feet long, constructed by native contractors working under the direction of the engineers. Although the railway owned some rock drills which they were prepared to lend, the contractors preferred hand work. Very strong men were required to handle heavy tools like drills, skilled fitters were almost unobtainable and were apt to blackmail the other workers, and the distance from workshops made any breakdown expensive. By making three shafts, giving eight working-faces in all, the work had been successfully completed in a reasonable time, but as it had been interrupted by civil war, no useful period could be mentioned. Fans had also been provided, but the contractors had preferred a very close atmosphere to the cost of operating them, and had made shift with a native contrivance worked by hand.

The political conditions under which the Khyber Railway had been built, and the employment of so many unskilled men, were noteworthy, indicating that there were still interesting and varied problems in engineering, and that railway work had not all been reduced to standard blue prints.

Mr. Lillie. Mr. G. E. LILLIE remarked that strategic railways, built to a scale far beyond the commercial requirements of peace time, were familiar enough in railway annals, but the strategic railways on the North-West frontier of India, which were in many ways unique, were by no means well known outside India. They had been built under conditions, and in an atmosphere, with which few were familiar, other than the military officers concerned and the Indian State Railway engineers—conditions that were difficult to visualize. Such a line was the Khyber Railway. Both the survey and location and the construction were remarkable, and the accounts given by the Authors were in both cases interesting; but perhaps the former opened up more leading questions, especially to those who had not

Digitized by Google

actually seen the line. The first of such questions was, why had steam and not electric traction been adopted? Possibly the vulnerability of the poles and electric wires in a tribal rising had been deemed to be a bar to the use of electricity. But, if so, it was permissible to ask—What about the permanent way and works? They were liable to be destroyed in a rising, and defensive arrangements were clearly necessary in either case. In some respects the line was ideal for electric traction. The gradients were bunched, and the power-plant could be concentrated quite near to the places where the power would be used, and placed inside a defended fort. There was, however, one respect in which electricity would lose some of its advantage, namely, the traffic was chiefly "through traffic" from down country, especially in times of military activity, when the line was subjected to its greatest test. That would involve most of the vehicles carrying supplies being hauled as trailer vehicles, which would reduce the adhesive weight. Still, all passenger-carriages could be changed at Peshawar or Jamrud, and electric motor-vehicles substituted at the same time as the electric locomotives were attached in place of the steam ones. In any case the percentage of the weight of the train that could be used adhesively for the purpose of traction would be far greater in electric working than in steam, and, of course, steeper gradients could be adopted. The Montreux-Oberland railway in Switzerland, an electrically-operated adhesion line, had ruling gradients of no less than 6·7 per cent., and trailing vehicles were hauled on all trains, their average being 33 per cent. of the total weight of the train. Other lines in that country had similar gradients. There would be little difficulty in operating the Khyber Railway electrically with a ruling gradient of 5½ per cent. That would surely have made it possible to dispense with the two reversing-stations between Bagiari and Shahgai, if not those beyond Landi Kotal also, and would have resulted in a simpler, cheaper, and less tortuous line, as well as in shortening the time of transit of trains and thereby increasing the capacity of the line, a most important point in time of war. It was not altogether clear why an easier gradient had been adopted for the rise from Bagiari to Shahgai than for that between Landi Khana and Landi Kotal. It would seem that the two reversing-stations on the former section were the price paid for those easier gradients. The two halts and the back shunt up a steep gradient constituted in practice a considerable delay, and hence reduced the capacity of the line, as well as increasing the cost of construction. The air-line gradient between the "jaws" and the edge of the Shahgai plateau, on a difference of level of 750 feet in 2 miles, was approximately 7 per cent., so that the substitution of

Mr. Lillie.

Digitized by Google

Mr. Lillie. a 4-per-cent. instead of a 3-per-cent. gradient should considerably reduce the sinuosity; and, if an electric line had been possible, the 5½-per-cent. gradient would have made it a fairly direct line. Colonel Hearn referred to the difficulty of making an adequate ascent with any given ruling gradient, owing to the necessity of interpolating level portions for crossing-stations. In such a mountain railway, especially when there was no wayside traffic (and consequently the trains ran through unless they had to stop to cross another train), there was no reason why the gradient should be interrupted for a crossing-station. The interpolation of a modified catch-siding (*Fig. 1*, p. 65) would have met the needs of the case with fewer drawbacks than a reversing-station; and, if the adoption of this idea had rendered the reversing-stations unnecessary, it would have saved a good deal of capital expenditure, as well as increased the capacity of the line. *Fig. 1* related to the hypothetical case in which the ruling gradient was 4 per cent., and the hillsides sloped across the railway at a uniform slope of 1 in 5. In such a station trains from opposite directions might be allowed to approach simultaneously without any danger, thus avoiding a delay inherent in ordinary single-line crossing-stations, for the two facing points F and F^1 would be rodded so that they would both be open for the sidings or open for the main line at the same time. There was another advantage of the same sort. The station siding (considering the whole of the level portion as the station siding) was entered by means of trailing points, by both up and down trains (points A and B). If, therefore, at A and B the special points were adopted which Mr. Lillie had devised for the Simla goods-station (where the station consisted of a system of level sidings on the contour of the hill and was entered by trailing points) there would be no possibility of a shunting vehicle breaking away on to the main line, and shunting could therefore be allowed to go on at any time, without restriction. The special points at Simla were "trailable spring points," that was to say, the switch was held in position by a weight in a small pit built alongside, which was lifted by the action of a train running through trailing (the normal position was, of course, for the siding). In addition, a locking arrangement was provided, which was actuated by a treadle-bar and locked the switches in whichever position they happened to be at the moment when the train reached the treadle-bar. The object of this was to prevent a train from being split and derailed if, in the act of running through trailing, it should stop before it was clear of the points, and back. With this arrangement, when once a train had got into the station siding, it could only get out again if the points-lever was unlocked and pulled over till the train got

Digitized by Google

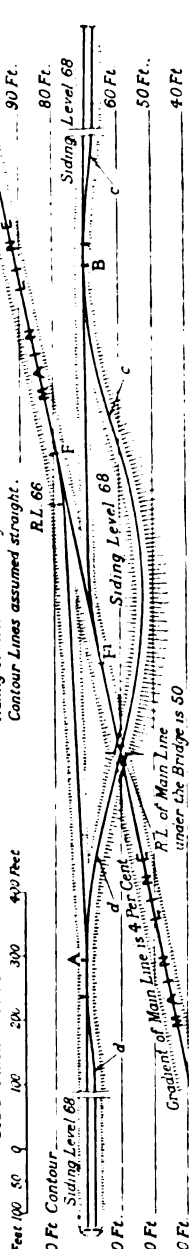


Fig. 1.

on to the treadle-bar: then the key could be removed and the lever returned to normal position (from which it could not be moved again without the key) when the train could safely pass on out of the siding. The keys of points A and B would, of course, remain in the custody of the station-master. In the case of the Simla goods-station the key was the "staff" of the section of the line leading to the goods-station, and thus the possession of that key by the driver was the sole authority for him to enter that section. The only drawback in this design of crossing-station was that a train detained there to pass another train had to be back-shunted from the one side of the station to the other; but this need not delay the train, for the shunting could be performed while it was waiting for the arrival of the other train. Indeed, if a slip line between c and c, and another from d to d were put in, the shunting could be done actually while the other train was entering the station.

Mr. Lillie.

No one would be rash enough to dispute the wisdom of the adoption of the standard broad gauge on such a line as the Khyber Railway, the very *raison d'être* of which was to pass the enormous bulk of military traffic from down country as expeditiously as possible, and without creating confusion, in the tremendous rush of a military campaign. It was therefore unnecessary to discuss the relative cost of a line on the 2-foot 6-inch gauge. But Colonel Hearn was on more controversial ground when he stated his belief that 800 feet radius was the practical limit for the sharpest curve an eight-coupled locomotive could work over, whatever the gauge. That limit was probably correct for the standard gauge,

Digitized by Google

Mr. Lillie. but for the 2-foot 6-inch gauge a 300-foot curve could be worked with similar facility by an eight-coupled engine. The 119-foot radius curves of the Kalka-Simla Railway (2-foot 6-inch gauge) had for years been worked by six-coupled engines.

Colonel Hearn's use of the aneroid barometer and the tacheometer for the preliminary survey work was particularly to be commended. Mr. Lillie had always found them of the greatest assistance and remarkably accurate if properly used. He also agreed with his strictures on the attempts (so commonly seen) to reduce to two places of decimals heights for contour and other similar figures.

Some idea of the difficult nature of the construction work was gleaned from the fact that all the cuttings had required the use of explosives, and in some cases the banks had had to be built from borrow-pits which themselves had required explosives for their excavation. Some of the banks would seem to be of considerable size—one contained 4 million cubic feet, and another was as high as 75 feet. It was a pity that more information could not be given as to the quantities of explosive required and the work done per unit of weight. There was a dearth of practical information on blasting work in India. The tunnel work, as usual, had encountered some unexpected difficulties, and the occurrence of pockets of soft stuff in the shale was interesting, especially the case in the Galo tunnel. The occurrence of pockets of wet stuff containing large quantities of water at so high an elevation, where to all appearances it might have so easily drained away, was, as the Authors said, mysterious. Mr. Lillie came across an extremely interesting case of that sort in the great famine of 1899-1900, in the plains of Rajputana. When the whole countryside was parched by the failure of the monsoon for 2 years running, and the wells and rivers were dry, it was a remarkable sight to see the villagers carrying chattis and other receptacles up the hill to Chitorgarh, where there was a large supply that lasted throughout the famine, to get water for their own use and to save a few of their cattle. The Chitorgarh hill, about 3 miles long and 1 mile broad, rose to a fairly uniform level of about 600 feet above the plains, a solitary excrescence from their dead level, looking like the inverted hull of some gigantic ship. This hill contained a large water-pocket and an underground reservoir of free water at a level not far from the top. This was tapped years ago and was accessible in a sort of stone trough which always remained full of water. The water saved many of the villages near-by in a famine that cost the State of Mewar more than half its population.

For a line of the exceptionally heavy character of the Khyber Railway, the bridges were inconsiderable, and there did not seem to

Digitized by Google

be anything unusual about them, unless it was the arrangements for dealing with the downhill thrust resulting from the braking of the trains on the steep gradients. It was satisfactory to learn that Colonel Hearn's formulas and methods for computing the waterway for the bridges and culverts had justified themselves. The catchments were, of course, all small. Colonel Hearn's method of dealing with arch culverts skew to the railway centre-line was not a very happy one. Mr. Lillie had built two such culverts in Rajputana in 1898, but he was dissatisfied with them—they looked unsightly and suggested the running away from a minor difficulty. The design also somewhat increased the masonry in the wing walls. The proper treatment of such cases was the time-honoured practice on British railways, whereby the arch was built as an ordinary square arch except for 3 feet at each end, in which the courses were curved so as to come square up to the face of the culvert, and skew-backs dressed in situ were cut to fit the curved courses. The design of the retaining-walls did not seem very pleasing, and did not dispose the masonry to the best advantage. Both Papers were silent on the defensive works required for military reasons, which must have been considerable and of importance. He would have liked also a description of the reinforced-concrete causeway. Mr. Lillie.

The Papers showed how great and how diverse were the difficulties met with in engineering construction in India, and the resource and ingenuity with which they were met.

Mr. T. R. NOLAN observed that Mr. Bayley drew attention to the provision to be made for horizontal stresses in bridge-piers and girders due to the braking or deceleration of trains while crossing them, and to the particular conditions which occurred on the Khyber Railway, where two bridges were constructed with the girders placed on gradients of 3 and 4 per cent. and where descending trains would be frequently checked by rapid deceleration. Mr. Nolan had had experiences in Assam of similar conditions, where he had had to deal with several major bridges built with the girders on gradients of 2·5 and 2·7 per cent. Several of those bridges had two or three spans of 100 feet, combined with shorter spans of various lengths and with piers as high as 70 to 80 feet. For piers exceeding 70 feet in height steel trestles were generally used, but there were some masonry piers of 80 feet. When these bridges were constructed the Indian Bridge Rules were not so comprehensive as they now were, and no special provision was made for the horizontal stresses in question. It had been found in practice, shortly after opening the line for traffic, that the girders in nearly every case tended to travel down-hill. Mr. Nolan.

Digitized by Google

Mr. Nolan. On some bridges the movement had been rapid and considerable; the girders had soon become jammed together, and had pressed so heavily against the ballast wall on the down-grade abutment that it was fractured and displaced. As a temporary expedient wooden blocks had been placed between the girder-ends, with a view to maintaining the correct spacing of the girders on the piers, rather than for the purpose of checking movement. This had become specially necessary on some long bridges on which the bearing of girders at the up-grade end of the bridge had run the risk of being dangerously reduced. The trouble had been overcome by fixing the lower end of each girder to the stone or concrete bed-blocks by means of lewis bolts, and at the same time taking care that no checking of rail-creep was attempted on the bridges, but that it was arrested as far as possible in the track for some distance from the up-grade abutment. This method had proved efficient and had resulted in no damage to the piers or bed-blocks. Several of these bridges were on 10-degree curves, and a lateral movement of the girders on the bed-blocks had caused some trouble; this had occurred mainly with the shorter and lighter spans, as spans of 60 feet and more were furnished with steel bed-plates which were so designed as to stop any such movement. The movement of the smaller spans had been stopped by cementing steel studs in the bed-blocks close up to the sides of the bearing-plates at the free ends of all girders.

Mr. Blair Ripley. Mr. BLAIR RIPLEY remarked that the Papers were of particular interest to him on account of his acquaintance with Major Anderson during the war. He had had the honour of commanding the First Canadian Railway Construction Battalion, and had come for considerable periods directly under Major Anderson, who was Railway Construction Engineer of the Fourth Army. The Khyber Railway seemed to be almost unique in more ways than one, and he did not know of any work in Canada that could well be compared with it. When the Canadian Pacific was built through the Rocky Mountains, there was in one place a considerable stretch of 4·4 per cent. gradient, but that was reduced to 2·2 per cent. in 1907 by the introduction of two spiral tunnels bored into the side of the mountains in order to secure the additional distance necessary to cut the gradient in two. The curves were much sharper than 7 degrees, which appeared to have been the maximum on the Khyber Railway. There were still curves in the mountains up to 14 degrees, and powerful locomotives were needed to operate them. No reversing-stations were employed on main lines, but on the branch line running into the mines at Rossland, British Columbia, there were reversing-stations, or "switchbacks," as they were sometimes called.

Digitized by Google

Mr. Blair Ripley.

Reversing-stations on the Canadian Pacific Railway differed from those on the Khyber Railway in that they could not be eliminated, since they were on the side of a slope that would not permit of any other system or alignment. Working in " tribal and unadministered territory " such as was described would no doubt be troublesome, annoying, and discouraging. Building railways in France and Belgium during the war had been bad enough, but there never had been doubt as to the attitude of the enemy. In this " tribal territory," he took it, there would be not only doubts as to enemy intentions, but also at times as to who were the enemy. It would be of little use to compare the costs of this great work with the costs of works done under more normal and peaceful conditions in Canada, and especially with works whereon heavy plant and equipment could be used. He was sure, from what he knew of such men as Major Anderson, that costs would be kept within bounds, and economies practised according to circumstances and best judgment. The method described by Mr. Bayley and applied to the Tangi bridge to eliminate horizontal thrust on the high masonry piers seemed to be a common-sense way of dealing with the situation. Mr. Ripley had had no occasion to use such a method, as in Canada there were no such heavy gradients on bridges, and rails were not anchored on such structures unless they were unusually long. He had greatly enjoyed Mr. Bayley's Paper, and appreciated some of the difficulties that had been overcome, especially in connection with the tunnel work. There must have been also some very nice instrument work, and he was sure Mr. Bayley could have said a great deal more, had he cared to do so. His Paper was highly instructive, and much credit was due to those who had carried out the enterprise.

Professor Royal-Dawson.

Professor F. G. ROYAL-DAWSON observed that, having had to give some attention to the project, as Chief Engineer with the Railway Board, when the details were under discussion, he was specially interested in Colonel Hearn's Paper, which brought out four highly satisfactory features. As to the gauge, since the line was primarily of a strategic nature, posterity would be grateful that the broad gauge had been adopted, that being the gauge of the parent line serving the railway. The disadvantages of narrow-gauge strategic lines had been demonstrated in the Kalabagh-Bannu (Trans-Indus) and Laki-Pezu Tank Railways (2-foot 6-inch gauge) during the frontier operations of 1917. Their ultimate conversion to broad gauge was inevitable. The next point on which Colonel Hearn, as Engineer-in-Chief of the project, was to be congratulated was that, having secured acceptance of the broad gauge, he had not prejudiced its future utility by the use of excessively sharp curves, as in the Sind-Pishin and Quetta-

Digitized by Google

Professor Royal-Dawson.

Nushki sections, where 10-degree curves (573 feet radius) were freely used with steep gradients, thereby restricting the wheel-base and consequently the tractive potentialities of the locomotives which had to work those sections. There had been abundant evidence of these limitations during the operations of 1917–19. Colonel Hearn's insistence on a minimum radius of 800 feet had been wise, as that curve would take a standard eight-coupled locomotive. But the matter did not end there. Lines of this nature might not have much traffic in normal times, but when an emergency arose, their capacity was taxed to the utmost. On such occasions, steep gradients such as 1 in 25 and 1 in 33 were the most serious obstacle to the movement of traffic, necessitating the breaking up of train-loads into two or more, even with the assistance of fairly powerful pusher locomotives. The delay was intensified by the fact that the line was single. In short, what was wanted for mobilization traffic in such localities (the Bolan route to Quetta with its 1-in-25 gradients being another example) was a mountain locomotive of special design, more powerful than any yet tried in India. Some form of articulated design was indicated. On the metre-gauge Hill Sections in Burma, gradients of 1 in 25 with 16-degree curves (358 feet radius) were successfully worked by Mallet compound engines. The Garratt type, with its somewhat widely separated simple high-pressure engines, had been in use for some years on the Darjeeling–Himalayan Railway (2-foot gauge); it freely negotiated curves of only 60 feet radius and also gave satisfaction on moderate gradients, but on gradients of 1 in 25 the adhesion was defective, owing primarily to the weight of water in the leading tank being automatically reduced as the gradient increased, and possibly to other structural details which might be improved. In any case, before conclusions could be arrived at as to the most suitable type for the broad gauge on a 1-in-25 gradient and a sharp curve, comparisons would have to be made by actual experiment. This involved a third point, which related to the prescribed running-dimensions for the broad gauge. On the metre gauge the ratio of width to gauge was 2·6 to 1, whereas on the broad gauge it was only 1·9 to 1. Although this ratio was not in itself a measure of efficiency (as was too often assumed in comparing one gauge with another), it happened in this particular connection that the greater overhang of the metre gauge permitted of the design of satisfactory Mallet engines, enabling low-pressure cylinders of suitable diameter to be placed outside the frame without exceeding the running-dimensions; whereas on the broad gauge, the width being restricted to 10 feet, the prescribed lateral space outside the frame was insufficient for such a purpose.

Digitized by Google

It had been estimated that to design a Mallet compound engine of 50,000 lbs. tractive force and 24-ton axle-loads, capable of climbing 1-in-25 gradients on the broad gauge, a loading-gauge of at least 11 feet 6 inches over cylinders, 12 feet width above platform-level, and 16 feet in height would be required. It was satisfactory to note that the tunnel sections had been designed to accommodate such running-dimensions, which were officially recorded as "maximum future running-dimensions." Incidentally, the Mallet type of locomotive was not the only one affected. The long body of the Garratt locomotive with its bogie wheel-bases at the extreme ends had considerable overhang in going round a sharp curve, so that a widening of the lateral structural dimensions would favour that type also. Or, alternatively, a larger boiler-diameter would enable the length to be shortened. All types would profit by the extra height, for it would then be possible to place the fire-box above the trailing wheels, instead of between them, as at present, thus enabling wider and more efficient grates to be used. In the foregoing remarks, the possibility of a 24-ton axle-load being needed in connection with the design of powerful mountain locomotives was implied. The fourth satisfactory feature brought out by the Paper was that the bridges had been designed to the most advanced standard loading recommended by the late Indian Bridge Committee (of which Professor Royal-Dawson was *ex officio* Chairman for some time), known as Standard 3. That standard, recommended for adoption in the most important bridges, especially in ghat sections where great adhesive weight was required, allowed of 24-ton axle-loads on an eight-coupled wheel-base. Thus in four particulars, namely, gauge, curvature, transverse clearances, and load standard, the Khyber Railway was blessed at the outset with assets of permanent value, which would go far to mitigate for all time the inherent disadvantages of steep gradients and reversing-stations.

Professor Royal-Dawson

Mr. R. STIRLING asked what the saving in cuttings, tunnels, bridging, and earthworks would have been had the minimum curves been 14 degrees (410 feet), instead of 7 degrees (818 feet). On the 3-foot 6-inch gauge Tocopilla mountain railway[1] by adopting minimum curves of 31 degrees (181 feet) the estimated saving on the 17-mile section of line, which traversed a rugged mountain range and attained a height of 3,285 feet in that distance, was very considerable. Articulated locomotives of Meyer-Fairlie type and bogie rolling stock were used. At first excessive wear of tire-flanges and rails had been experienced, which had been only mitigated

Mr. Stirling.

[1] Minutes of Proceedings Inst. C.E., vol. cxlii (1900), p. 89.

Digitized by Google

Mr. Stirling. by the use of the hardest steel obtainable; but subsequently, by lubricating the locomotive tire-flanges with heavy petroleum residue, the tire- and rail-wear had been reduced to quite normal proportions. Earlier attempts at lubricating the tire-flanges had failed, because the oil used had spread over the rails; but petroleum residue, being practically free of the lighter lubricating fractions, had not this disadvantage. The life of locomotive-tires, which at first averaged only 30,000 to 40,000 miles, had been increased to more than 200,000 miles. The life of rails and car-tires had been increased in like ratio. Thus the only serious drawback to such sharp curves had been overcome. Locomotives of 60 tons adhesive weight were in use with rails weighing 50 lbs. per yard, so that, with 90-lb. rails, adhesive weights of 100 tons could be obtained, obviating the necessity for a locomotive pushing at the rear of the train, as mentioned by Colonel Hearn—a somewhat dangerous practice on such a railway. A speed of 15 miles per hour on 4-per-cent. gradients was probably the economical limit for up traffic, and the same for down traffic, even with continuous brakes, so that the super-elevation of $3\frac{1}{2}$ inches need not be increased for curves of 410 feet radius. This was almost proportionate to the superelevation which had proved satisfactory on the Tocopilla Railway. Compensation of 1 per cent. on the 181-foot curves had proved to be more than was required. It would seem that only the strategical position of the Khyber Railway could justify the extra expenditure due to the adoption of 7-degree curves, seeing that the sole advantage was that the standard rolling stock of the Indian railways could be used. Even so, the locomotives were admittedly unsuitable for working traffic on 4-per-cent. gradients.

Mr. Stringer. Mr. H. STRINGER observed that the following observations on the use of the Talbot formula might be generally useful, since this formula was used widely and taken too literally. The formula was $a = C^4\sqrt{A^3}$, where a denoted the required area of waterway in square feet, A the drainage-area in acres, and C was a coefficient ranging from $\frac{2}{3}$ to 1 for steep rocky ground. For rolling agricultural ground where the length of the valley was three or four times its width, C might be $\frac{1}{3}$, and it could be reduced to $\frac{1}{5}$ or $\frac{1}{6}$ if the stream was longer in proportion to the width of valley. The coefficient C should be increased for steep side slopes, and especially if the upper part of the valley had a steeper fall than had the channel at the culvert.

The following flood-records were obtained for semicircular arch culverts in 1923. These culverts were 6 feet from invert to springing, 70 square feet in area, and, according to the Talbot

Digitized by Google

formula, capable of draining 289 acres, the constant being taken as one for steep rocky ground. Mr. Stringer.

No.	Drainage-Area.	Max. Length Watershed.	Flood above Invert.	Average Slope Stream-Bed.	Remarks.
	Acres.	Feet.	Ft. In.		
1	86	3,000	8 0	3° 28′	Rainfall 4⅜ inches in 2 hours. First three culverts all within 1 mile. Upper slopes of 8° 30′ to stream-bed. Sides almost vertical and very deep.
2	74	3,000	8 0	3° 49′	
3	81	2,800	8 0	3° 53′	
4	240	3,900	5 0	5° 52′	Rainfall 3 inches in 3 hours. Culverts all within 1 mile. Beds not deeply cut and sides not steep.
5	270	3,000	5 5	5° 31′	
6	170	1,500	2 4	4° 30′	
7	400	10,000	4 0	1° 30′	

The average slope of the bed was obtained by measuring the length from the upstream culvert-face to the farthest part of the watershed divide, and observing the height of this point above the culvert-invert. The foregoing results showed that the Talbot formula was inapplicable to ravines where, as in the first three cases cited, the channel had extremely deep and very steep sides. It would appear that side-slope conditions and not bed-slopes were the determining factors for maximum quantity at culverts. Apparently the Talbot formula should be weighted with a constant of about 4 for culverts with the characteristics of Nos. 1, 2 and 3 in the above Table. He suggested that the sections of the drainage-areas at the railway should be taken as a rough guide for fixing the value of the constant in the Talbot formula for small areas where the time factor was of no account. The character of the foundations also had a bearing on the fixing of culvert sizes, since where rock was a certainty more chances were taken, as was the case also where bank-heights were insignificant and serious consequences from washouts were thus not anticipated. He would be glad of information as to the method of excavation adopted in the Khyber for foundations in what must have been boulder-strewn beds. Had open wells been used at all? Also, was any use made in India of lime-and-mud concrete in this connection? A concrete that had been in use in China for generations consisted of a mixture of dried mud and slaked lime, in the ratio of about 6 to 1, rammed in 6-inch layers with a four-man rammer. The safe load was between 2 and 3 tons per square foot. It was extensively used in minor bridges, culverts, and buildings located on banks. In the Nan Ling tunnel (built in 1923) on the Peking-Mukden Railway, 3,895 feet in length, hand drilling had been preferred by

Digitized by Google

Mr. Stringer. the contractor, though power drills had been available. The same applied to heading-ventilation, where native-made hand-driven fans had been employed. The concrete-block method of arch-lining, also adopted in that case, would appear to have obvious advantage in securing an adequate thickness of arch. Was the practice of contouring culverts to reduce length standard practice on first-class work in India? With regard to minimum curvature and type of locomotive, eight-coupled locomotives were successfully worked on the Benguella and Rhodesian Railways over 100-metre curves, on 60-lb. rails with 1,920 steel sleepers to the mile.

Mr. Bayley. Mr. BAYLEY, in reply, remarked that it would appear from Mr. Nolan's experience of the effects of creep and of braking stresses on high girder bridges on steep gradients, that such bridges should, if possible, be sited so that the last down-grade span could bear against an abutment in solid ground, and that anti-creep devices should not be used on the bridge. Under such conditions the opinions expressed favoured the provision of wooden blocks between the ends of girders. When the bridge could not be sited as indicated above, a substantial down-grade abutment seemed to be necessary. In the girder bridges across the Khyber nullah, the curtain walls had been taken down to the full depth of the foundation. The nullah-bed consisted of compacted boulders and shingle to an unknown depth. The nullah fell at an average slope of 1 in 50, and scour was terrific. It had been desirable to limit this scour to a definite depth by providing a continuous floor between the curtain walls, not only in order to preserve the foundations, but also to keep the nullah bed-level constant in the neighbourhood of the bridge. No undue heading-up of flood-water occurred, beyond the usual afflux at the bridge, because both the railway and the nullah were winding down a ravine at an average slope of 1 in 50, and consequently, long before heading up could occur to any significant extent, surplus water would flow over the nullah-bank and seek a new flood-channel. Mr. Lillie had referred to the possibilities of electric traction, which were undoubtedly important. The capital cost, however, of providing and keeping unused sufficient electric power-plant and rolling stock to deal with the emergency of war would need to be considered, and this doubtless had led to the decision to build the Khyber Railway so that ordinary steam rolling stock from any other 5-foot 6-inch gauge railway could run over it.

It was probable that in several tunnels where removal of the spoil had proceeded regularly petrol tractors would have been economical. Most of the tunnels, however, were in difficult ground, where the rate of progress had not been governed by the rate of removal, and

Digitized by Google

in such cases it was likely that overhead charges on powerful tractors capable of working up 4 per cent. gradients, and kept idle for considerable periods, would have absorbed the savings. Mr. Bayley.

He had made no use of mixtures of Portland cement and lime or of lime-and-mud concrete. Lime concrete for small culvert arches had often been used in India with success where suitable lime mortar was available. He was particularly grateful to Mr. Royal-Dawson for his observations, which were not only of great intrinsic interest, but also answered many points raised by other correspondents. He would leave it to Colonel Hearn to reply on all matters relating to the survey and location. He desired, however, to place on record his admiration of the survey carried out by that officer, whose bold and magnificent conception of the Khyber Railway had been amply confirmed during its construction. Mr. Bayley considered it to be a classic example, which would be a model for similar work for many years to come. In conclusion he desired to thank the members for their useful and instructive comments on his Paper.

Colonel HEARN, in reply, remarked that he was gratified to observe the interest displayed in the Papers, as evidenced by the volume of the Correspondence. To reply on all the points raised would involve the writing of a second Paper, but some of them he was precluded from dealing with, for certain reasons. Colonel Hearn.

It was hardly the case, as suggested by Mr. Johnson, that he had a predilection for the aneroid barometer out of its usual sphere. In the preliminary reconnaissance, with due correction for temperature conditions and the " diurnal wave " (of considerable proportions near Peshawar), it had been of great use for ascertaining the heights of controlling points. In the reconnaissance, or rough, survey, which followed, the aneroid had been very useful for obtaining additional heights not easily obtainable otherwise. But there its use ended, and he recognized that it was only occasionally that anything approaching close accuracy could be obtained.

Nor had the tacheometer been used reluctantly, as it seemed to Mr. Burton, or on account of the employment of Indian assistants, who used the instrument with the best results. The absence of vegetation gave an almost ideal condition, and Colonel Hearn had used the tacheometer even in dense forest for more than 20 years. But the ground in the Khyber was so broken that it had been found advisable to draw the contours in the field on the plane-table sheets after the reduced heights had been plotted in the office: contouring the sheets in the office would not have been satisfactory, although under other conditions that would have been quite

Digitized by Google

Colonel Hearn. adequate. He was conversant with the use of Jordan's tables, but the diagrams he had prepared saved much time by comparison.

Some criticism had been aroused by the mention of the levelling and check levelling of tacheometer stations. But it was known from the rough survey that no error could be allowed, if the severe gradient was to be run through evenly and danger of "stalling" avoided. A little later a former member of the staff wrote to him for advice, as that engineer had found a gradient of 1 in 20 on a railway, the supposed ruling gradient of which was 1 in 25. It was, of course, difficult to satisfy a critic who had not seen the country, and necessarily the plans had been much reduced, involving omission of detail. But no one had been able to suggest a better alignment; in fact in the highest quarters the location had been described as a "masterpiece."

To some of the criticisms on the gradient adopted it was not possible to reply fully, but the best gradient obtainable had been adopted, and even 1 in 25 was worked daily on the Quetta Division for much longer distances than in the Khyber. The use of a much steeper gradient by "rack" operation had been considered, and had required further work during the survey. But it had been felt that such a railway, with very light traffic at the start, but capable at any moment of a great expansion of traffic, should be operated by a type of locomotive in common use elsewhere, instead of tying special types to a short length of railway and locking up capital. To have introduced electrification, as suggested by Mr. Lillie, would have had the same result; for even had power been available, the transmission system and special stock would have been a heavy charge, not to be compensated by saving on works. These matters had been fully considered.

Exception had been taken to his opinion that a 7-degree curve (818 feet) was the "practical limit" for operation by eight-coupled locomotives, whatever the gauge. He was well aware that much sharper curves were operated daily by such locomotives; but at what expense? In the first place, the length of railway was much greater, on account of the loss of fall due to compensation, and the maximum gradient had to be overcome over the additional distance, thus in effect giving a greater height to be surmounted. Some saving in individual works resulted, but, unless the curve adopted suited the contours, there was not necessarily a large saving, especially as increased superelevation lengthened the tangents. No curve in reason suited some of the ground, and the relaxation of standard tended to less careful location. Cuttings and tunnels and station works must be widened. He was prepared in exceptional places

Digitized by Google

to adopt an 8-degree or even a 10-degree curve, but he could find no real justification on the ground of saving of works. He avoided the expense of check-railing; he hoped that wear of rails and tires would be relatively low, and no doubt Mr. Stirling's information as to the benefit of petroleum residue would be of use. But the Kalka–Simla Railway was an example of terrible wear of rails and tires and heavy sleeper-renewal, due to the very sharp curvature mentioned by Mr. Lillie, whose design for a crossing-station was largely discounted by the fact that the contours were heavily curved, with a side slope much worse than 1 in 5. When the line worked to its full capacity, crossing at almost every station would be required, and a traffic diagram had been prepared at a very early stage. There were other features of this suggestion which he considered objectionable, and a catch siding had been omitted. The compensation of gradient for curvature was 0·3 per cent. for a 7-degree curve. Colonel Hearn.

He agreed with Mr. Bourne—as was evident from the Paper—that the rolling of plans was objectionable. Mr. Bourne had not quite grasped the Work Number System. Ordinarily each cutting, with the adjoining bank, was given the appropriate consecutive number, but a viaduct or tunnel with approaches, the works at a station, the water-supply pipe-line, a defended camp, and a quarry, were instances of the grouping of works. The total number was about 200. Allocation was not affected. The cost of a culvert in a certain Work Group (perhaps a better name than a Work Number) would be allocated to Minor Bridges iv (b). So long as the allocations to Work Group and sub-head of account were carefully made, one clerk sufficed to keep up the Index Expenditure Card for the Chief Engineer. Mr. Bourne had not quite appreciated the reference to 10 per cent. of the expenditure having been caused by special features not likely to be found elsewhere. The estimated cost had been exceeded by more than that percentage, and although this was largely due to the necessary distribution of work to inexperienced contractors, often too proud to take advice, the avoidable excess on this account could not be estimated. Mr. Bayley's Paper showed that some tunnels had been constructed for nearly the estimated cost, others had not, and the construction had taken longer than was anticipated, partly due to lack of funds at one period, although this was not all loss.

Mr. Bourne was mistaken in thinking that he questioned the wisdom of using lime-surkhi arch-rings in the small culverts. The increased cushion of earth provided, and the tests of the material by previous experiment, made him confident of their stability increasing with age. The use of floors and drop walls was universal,

Digitized by Google

Colonel Hearn. even in the main Khyber stream, and no open wells had been employed. The beds were not only boulder-strewn, but were also composed of boulders and flakes of shale to a great depth. Sinking would therefore have been very troublesome. It seemed that the methods adopted were quite efficient and probably much cheaper. Mr. Stringer's exposition of the Talbot formula was welcomed, but, as usual, the coefficients had to be used with care, and the examples given seemed to show that those adopted were by no means correct. Mr. Leitch's questions on the subject would demand an extensive reply, but it must be admitted that restriction of waterway involved banking-up of a flood, though not so great in the case of these bridges, where the outfall was free and on a considerable slope (1 in 50 or more). He could not agree with Mr. Lillie that the battered wing-wall design did not make the best disposition of the masonry.

Mr. Stringer's description of the use of lime-and-mud concrete was interesting, but clay or mud was hard to find in the Khyber, and the quantity required to build the temporary quarters mentioned had had to be carried a considerable distance.

As to the movement of girders on a gradient—referred to in Mr. Bayley's Paper—Colonel Hearn had specified angle sections to butt against the piers or abutments—not to take any braking stress (which he considered would be absorbed by the permanent way above the bridge) but to counteract possible downward creep of the girders due to expansion and contraction. He understood that the Government Inspector of Railways had ordered the removal of those angles, but Major Anderson's experience on the Quetta Division seemed to corroborate his own opinion.

Other points of detail mentioned he must regretfully avoid, except the matter of pockets of water, on which point Mr. Lillie's account of Chitorgarh had interested him, because recently a friend had suggested that condensation of moisture might be the cause of infiltration and retention in certain pockets or impermeable strata. This would occur in the Khyber during winter rains or occasional summer storms.

Digitized by Google

9 March, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D.Eng., President, in the Chair.

THE Council reported that they had recently transferred to the class of

Members.

BERNARD JAMES BELSHER.
PERCY WALTER BERTLIN.
FRANK HUNTINGDON CORSON.
JOHN MUIR DONALDSON, *M.C.*
CONRAD GRIBBLE.
ARTHUR GEORGE CECIL FANE, *M.C.*
WILLIAM MURRAY PULLAR, B.C.E. (*Melbourne*).
GEORGE EWART RHODES.
FREDERICK NICHOLAS GLOVER TAYLOR.
WAUDE THOMPSON.
ARTHUR MAURICE WARD.
ALLAN GRIFFITHS WATSON.
JOHN STEVENSON YOUNG, B.Sc. (*Victoria*), B.Eng. (*L'pool*).

And had admitted as

Students.

THOMAS NEVILLE ADAMS.
ARTHUR LEMPRIERE LANCEY BAKER.
FREDERICK STUART BLOOMFIELD, B.A. (*Cantab.*).
DAVID JAMES DAVIES.
RUDOLPHE DAVISON.
JAMES FREDERICK FIELD, B.Sc. (*Edin.*).
GRAHAM FRANK GEORGE.
JACK STUART GODWIN.
ALFRED SAMUEL KNOLLES, B.Sc. (*Durham*).
THOMAS LAWRIE, B.A. (*Cantab.*).
JOSEPH WILLIAM BRAITHWAITE LENG, B.Sc. (*Durham*).
WILLIAM LINN.
ALBERT LEONARD LYON.
WALTER NORMAN MCCALL.
DUNCAN MACKENZIE MACTAVISH, B.Sc. (Eng.) (*Lond.*).
PERCY JAMES MADDICKS, B.Sc. (*Edin.*).
HORACE DENTON MORGAN.
WILLIAM THOMAS OWEN, B.Sc. (Eng.) (*Lond.*).
HARRY STEWART ROBINS, B.Sc. (*B'ham.*).
ROBERT DOUGLAS ROBINSON.
KENNETH PATRICK RUSH, B.Com. (*Lond.*).
HUGH AYMER VALLANCE.

The Scrutineers reported that the following candidates had been duly elected as

Associate Members.

ALEXANDER KEITH ANDREW, *M.C.*
DUNCAN CAMPBELL BERRY, B.Sc. (*Leeds*).
JOHN KENNETH BROOKS, Stud. Inst. C.E.
DERRICK CHARLES BROWN, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
WALTER COLIN BUDD, Stud. Inst. C.E.
AMRITA GOPAL CHATTERJI.

Digitized by Google

Associate Members—continued.

James Comrie, B.Sc. (*Edin.*), Stud. Inst. C.E.
Charles Harold Cottew.
Thomas Burnaford Davey, B.Sc. (Eng.) (*Lond.*).
William Whitridge Davies, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
George Alexander Dawson, B.Sc. (*Glas.*).
John Alexander McKinnon Donnelly, Stud. Inst. C.E.
Sidney Leopold Engel, Stud. Inst. C.E.
Walter John Evans, Stud. Inst. C.E.
John Kenneth Fisher, B.Sc. (Eng.) (*Lond.*).
Aage Gernow.
Oswald Wellington Gilmour, B.A., B.A.I. (*Dubl.*), Stud. Inst. C.E.
Gerard Stafford Staveley Gordon, *M.C.*, B.A. (*Cantab.*).
Richard Cooper Gowthorpe, B.Sc. (*Manchester*), Stud. Inst. C.E.
Bernard Hackforth, B.Sc. (Eng.) (*Lond.*).
Ivan Harrison Hainsworth, Stud. Inst. C.E.
John Alexander King Hamilton, B.Sc. (*Edin.*), Stud. Inst. C.E.
George Armor Harris, B.A., B.A.I. (*Dubl.*).
Percy Charles Greenwood Hausser, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Henry Alexander Henry.
Alastair Macgregor Herd, B.Sc. (*Glas.*), Stud. Inst. C.E.
Vivian Dottin Joll, B.Sc. (*Bristol*), Stud. Inst. C.E.
Julius Kennard, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
William Arthur Kirk.
William Arthur Knighton, Stud. Inst. C.E.
William Cuthbert Knill, B.Sc. (*Durham*), Stud. Inst. C.E.
Ernest Gordon Lee, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
William Gordon Lees, B.Sc. (*B'ham.*).
Thomas William Marsh, B.Sc. (Eng.) (*Lond.*).
Hugh Francis Molony, B.A., B.A.I. (*Dubl.*), Stud. Inst. C.E.
Tuppaige Peter de Silva Munasinghe, Stud. Inst. C.E.
Arthur Benjamin Newby, Stud. Inst. C.E.
Harold Arthur Wellesley O'Connor, B.Sc. (*New Zealand*), Stud. Inst. C.E.
Alexander Cay Owen, B.E. (*New Zealand*).
William Parvin.
Harry Reid Paton.
John Penman.
John Reid.
Kenneth Rowell, B.Sc. (Eng.) (*Lond.*).
Sydney Walter Saunders, B.Sc. (Eng.) (*Lond.*).
George Stanley Hamilton Shaw, B.Sc. (Eng.) (*Lond.*).
William Sleight, B.Sc. (*Leeds*), Stud. Inst. C.E.
Clifford Bevous Smith.
Denis Distin Stedham, Stud. Inst. C.E.
Arthur Stowers, B.Sc. (Eng.) (*Lond.*).
John Matthew Blackwood Stuart, B.A., B.A.I. (*Dubl.*).
Gordon Ralph Walter, Stud. Inst. C.E.
William Ernest Chadwick Ward.
John Francis Woollcombe, B.A. (*Cantab.*).
Thomas William Wragg.

Associate.

Major Albert Edward Macrae, *R.A.*

Digitized by Google

The following Paper was presented for discussion, and, in the absence of the Author abroad, Mr. A. G. Vaughan-Lee, M. Inst. C.E., exhibited a number of lantern slides illustrating the work. On the motion of the President, the thanks of The Institution were accorded to the Author.

(Paper No. 4568.)

"The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile."

By Oswald Longstaff Prowde, B.A., M. Inst. C.E.

Introduction.

The Gezira plain lies between the Blue and White Niles in the Anglo-Egyptian Sudan. The position of the irrigation scheme is shown in Fig. 1, Plate 2. Up till now millet has been the only crop grown on this plain; but the tropical rains on which it is dependent are extremely variable, and the crop is precarious. Soon after the reconquest of the Sudan in 1898, the possibility of irrigating the Gezira was recognized by the late Sir William E. Garstin, Hon. M. Inst. C.E., and from 1904 preliminary investigation work was carried out by the Sudan Branch of the Egyptian Irrigation Service, under Messrs. C. E. Dupuis, M. Inst. C.E., and P. M. Tottenham.

In 1911 experiments were begun by the Sudan Government to investigate the possibility of the cultivation of cotton; and at the pumping-stations which were erected it was found that this could be successfully grown during the flood season, when there is an ample supply of water. In the Sudan the annual rise of the Blue Nile commences about the middle of May and reaches a maximum at the end of August, gradually falling to a minimum at the middle of the following May. In Egypt the climatic conditions are such that cotton must be planted in March, and so is in need of irrigation water when the Nile is at its lowest. By planting on the rising flood in July the cotton on the Gezira is assured of an ample water-supply, and the only difficulty occurs in February and March, towards the end of the period of cultivation, when stored water is necessary.

Digitized by Google

The general slope of the Gezira is from south-east to north-west, and therefore it can only be irrigated from the Blue Nile, which, however, even at its highest level, runs several metres below the level of the plain.

The only suitable site for a dam was at Makwar, a village on the Blue Nile, 7 kilometres above Sennar, and 277 kilometres above Khartoum. Borings were made here and preliminary designs prepared, which were examined in 1913 by a Commission consisting of the late Sir William Garstin, and the late Sir Arthur L. Webb, Sir Murdoch MacDonald, and Mr. H. H. McClure, MM. Inst. C.E.

During the spring of 1914 houses for the staff and workmen, stores and workshops, etc., were built, plant and other equipment were purchased, and staff were engaged. Owing to the war the works were closed down in the autumn and remained in that condition until 1919. Work was then restarted, the principal item being the erection of a cement-factory.

Work on both the dam and the canalization proceeded during 1919 to 1921, being carried out by the Sudan Construction Company on a percentage basis, but owing to the large increase in world prices and to the lack of necessary funds, the works were temporarily stopped in April, 1922, the percentage contract being cancelled.

Further funds were obtained in the summer of that year, and six English firms of contractors were asked to tender on a fixed-rate basis, which was then possible. The lowest tender was received from Messrs. S. Pearson and Son, Ltd., with whom a contract was signed by the Sudan Government in October, 1922, for the completion of the works by July, 1925. Work recommenced in December, 1922, and the dam was successfully completed by the end of May, 1925, the canals being finished by the end of June.

Almost all plant and materials from abroad were imported by means of the Sudan Government Railways from Port Sudan. The Nile route was used largely by the staff and for the carriage of Egyptian labour, which reached a maximum of 10,000 men in 1924. The total number of workmen employed in that season was 20,000, the other 10,000 being Sudanese.

The average daily maximum temperature in the shade for the whole year is 100° F. The heaviest rains occur in July and August, and during the rains the roads, which are merely earthen tracks, become almost impassable. The bulk of the work, therefore, must be done in the dry period between October and July. When the river is high, it is impossible to do any work in the actual river-channel; and malaria is prevalent during August, September, and October. Everything possible was done to keep malaria to a

Digitized by Google

minimum, but although it was largely reduced, it was never entirely eliminated. During the course of the work, from 1914 to 1925 there were 342 deaths, 45 due to accidents and 297 to disease.

The drinking-water supply was obtained from the river upstream of the dam site. The population on its banks south of the dam is small, and consequently the water is free from pollution. It was simply filtered by the local earthenware "zeers." During the flood, however, when the river was laden with silt, the water was passed through settling-tanks. Practically no cases of illness could be attributed to the water-supply.

The cost of the works was—

Sennar dam	LE. 5,600,000
Canalization.	LE. 2,900,000
Total	LE. 8,500,000

(One Egyptian Pound (LE.) = £1 0*s.* 6*d.*)

Sennar Dam.

Design.—The dam (Figs. 2, 3, 4, and 5, Plate 2) is built of granite rubble masonry. The central portion, principally in the original river-channel, consists of a pierced dam 606 metres in length with eighty main sluices, above which are seventy-two small spillways. At each end of the sluice dam there is a spillway portion 150 metres in length, containing twenty large spillways (forty in all). Beyond the east spillway is a portion of solid dam 137 metres long; on the west there is a similar portion 439 metres in length, which is followed by the main canal head regulator, 125 metres long, consisting of fourteen sluices. At each end of the dam there is a masonry corewall with a rubble and earth bank behind. These are 583 and 835 metres long on the west and east sides respectively.

In calculating the cross section of the dam, the weight of the masonry was assumed to be 2·3 metric tons per cubic metre (144 lbs. per cubic foot). The head was taken from roadway-level 421·70 upstream[1] to the lowest point of the foundations downstream. Usually the water-level downstream will not fall below Reduced Level 404, and when this occurs the water-level upstream will be less than R.L. 420·70. It is possible, however, that it may be necessary to dry off the area downstream of the dam in order to build aprons. The method of calculation of the stresses in the sluice dam was similar to that used for the Assuan dam, which has been described

[1] All levels are in metres, and they refer to the zero of the Nile gauge at Khartoum, which is assumed to be 360 metres above sea-level at Alexandria.

Digitized by Google

by the late Sir Maurice Fitzmaurice, Past-President Inst. C.E.[1] In dealing with the masonry down to the sill of the sluices, it was assumed that the length of 5 metres of masonry between the sluices took all the pressure of water over the length of sluice and masonry, which is a safe assumption. Below the level of the sills of the sluices the lengths of masonry and water are equal, and the weight of all the masonry above the sluices was considered to be effective.

The design of the dam was checked for considerations of possible water uplift by Dr. P. Phillips, of the Physical Department of the Egyptian Government, and was found to be stable. The maximum pressure on the masonry at the deepest point of the foundations, with the reservoir full, was calculated to be 7·03 kilograms per square centimetre (6·43 tons per square foot) on the downstream side, and with the reservoir empty 8·01 kilograms per square centimetre (7·32 tons per square foot) on the upstream side. Uplift has been neglected in these calculations.

The principal dimensions of the dam are—

Length	metres	3,025
Quantity of masonry	cubic metres	422,440
Greatest height from the lowest point of the foundations to the top of the parapet-coping	metres	39·5
Coping-level	metres above sea-level	422·60
Roadway-level	,, ,, ,,	421·80
Roadway-widths (inside of parapets)—		
Corewall	metres	4·40
Regulator	,,	3·70
Solid dam	,,	3·80
Spillway dam	,,	5·30
Sluice dam	,,	5·30
Sill-level of regulator sluices	metres above sea-level	411·25
Width of large spillways	metres	5
Height from sill-level to spring of arch	,,	2
Sill-level	metres above sea-level	417·20
Width of small spillways	metres	3
Height from sill-level to spring of arch	,,	2
Sill-level	metres above sea-level	417·20
Width of main sluices	metres	2
Height from sill-level to spring of arch	,,	8·4
Sill-level upstream	metres above sea-level	404·20
Reservoir level upstream	,, ,, ,,	420·70
Highest flood recorded (1917), discharge in cubic metres per second		10,000
Highest known flood (1878), estimated discharge in cubic metres per second		12,000

[1] Minutes of Proceedings Inst. C.E., vol. clii (1903), p. 88.

Digitized by Google

Possible maximum flood allowed for, discharge in cubic metres per second	15,000
Estimated level of maximum flood upstream with all sluices and spillways open . metres above sea-level	421·40
Estimated level of highest known flood (1878) downstream . . . . . metres above sea-level	415·70
Estimated level of maximum flood downstream metres above sea-level	416·70

The Sudan Government Railway runs across the dam, and it will be extended later to join the new line which has been constructed from Port Sudan to Kassala.

No locks were built, since the heavy extra expense was not considered justifiable. The Blue Nile is only navigable for a few months during the flood, and even before the dam was built almost all traffic was transferred to or from the railway at Sennar, whence the mail-steamer went south as far as Roseires. In future all river traffic will commence upstream of the dam. The extent of native sailing-boat traffic on the Blue Nile is small. When the river is navigable the wind is in the same direction as the river-current. Conditions in Egypt are entirely different: the Nile is navigable throughout the year, and the wind blows almost continuously from the north; native boats can therefore sail upstream or float down with the current.

Foundations.—The whole of the masonry dam, with the exception of the corewalls, is founded on sound gabbro rock. The rock, which is of igneous origin, has a high specific gravity of about 3·05. The site was explored, with the assistance of Mr. G. W. Grabham, the Sudan Government geologist, by means of borings and, where possible, by open pits. The average actual level of the foundations proved to be above the estimate.

Above the sound rock was a stratum of decomposed gabbro. The decomposition has taken place along joints, so that the rock has been reduced first to a mass of boulders with decomposed material between them. In the upper parts, where the process is complete, the rock has been entirely decomposed. Above this decomposed gabbro there was in some places a layer of ironstone conglomerate, in others the decomposed gabbro was overlain by the river alluvium. At the two ends of the dam the surface material was the brown loess clay of the subsoil of the Gezira plain.

The corewalls were founded in different materials, namely, decomposed gabbro, ironstone conglomerate, and loess clay, the depth of these foundations depending on the head of water on the dam and on the foundation material. Experiments carried out to

Digitized by Google

test their impermeability showed that the decomposed gabbro would stand a head of more than 12 metres on a length of 0·5 metre, the loess 14 metres, and the ironstone conglomerate 4 metres. Even the last-mentioned figure allows a large margin of safety in the actual dam, where the head ranges from 5 metres to zero.

Springs.—In all, 182 springs in the foundations were dealt with, but none discharged any large quantity of water. They issued from joints between boulders of sound gabbro; and in no instance could they have exerted more than a purely local pressure on the masonry of the dam. The usual method of sealing them was to build the masonry round the spring and so form a well, in which the water was kept below the level of the top of the surrounding masonry by pumping. When the water-level was steady, the well was pumped out and cleared, and about 1½ metre depth of dry rubble was thrown into it. In this rubble two vertical iron pipes of 3 or 4 inches diameter were placed, their lower ends being at different levels. These pipes were continued up above the level of the surrounding masonry. Masonry was then built above the dry rubble to the top of the well. When this was set, the well was grouted with neat Portland cement which was forced down one pipe until it appeared at the top of the other. The top of the second pipe was then capped, and an air-compressor forced grout down the first pipe under pressures up to 25 lbs. per square inch, until no further grout could be introduced. The compressor was also used at the commencement of the grouting to clear out as much water as possible from the bottom of the well.

Masonry.—The mortar used for the granite rubble masonry consists of 4 parts of sand to 1 of red cement. On the upstream face a width of 1·50 metre is built in 3-to-1 Portland-cement mortar. A similar mortar was also used for a depth of 0·60 metre on top of the foundation rock. The facework is rubble mosaic, pointed with 2-to-1 Portland-cement mortar. The sluices are lined with granite ashlar set in 3-to-1 Portland-cement mortar and pointed in 1-to-1 Portland-cement mortar. The granite for the rubble masonry was at first brought from Gebel Moya, 35 kilometres from the dam, on the Sudan Government Railway, and later from Gebel Seggadi, a distance of 52 kilometres by rail, at which latter place all the granite ashlar was cut. The sand was obtained from the bed of the Nile. It was sharp, clean, and contained some gravel, the greater part being pumped out by a suction dredger. Generally mortar was made in Stothert-Pitt 1-cubic-yard mixers. From the mortar returns it is calculated that the rubble and ashlar masonry contains 40 per cent. of mortar on the average. The Portland cement conformed

Digitized by Google

to the British Standard specification. Red cement, the specification for which is given in Appendix A, consisted of 70 parts of Portland-cement clinker and 30 of burnt clay, locally called "homra." These were ground intimately together in the factory. It was found that red-cement mortar 12 months old was equal in tensile strength to mortar made with Portland cement. The results of the tests are given in Appendix B. The substitution of burnt clay resulted in a saving of about LE. 1 per ton of cement.

Mr. J. V. J. Hayman, F.I.C., in an (unpublished) report on the subject of red cement, states that :—

"The characteristics of red cement are, in the early stages, little difference in setting time to that of the original cement but considerable difference in strength. From 7 to 28 days the increase in strength is very notable in the case of red cement.

"The use of a puzzolanic material like homra in cement is correct. Cement consists mainly of silica combined with as large a proportion of lime as is consistent with freedom from expansion. In this cement there is no free lime, but the moment water is put on it the compound separates into a lower silica-lime compound and free lime, the setting and strength being due to the crystallization of lime. All this can be seen under the microscope.

"The 'lime' crystals contribute little strength to the mortar and under some conditions lime can be removed from the mortar. Adding a puzzolanic material gives this 'lime' something to combine with, thus increasing the strength of the cement."

Owing to delay in the completion of the cement-factory, 54,860 cubic metres of rubble masonry in the dam were built in 1921 and 1922 with a mortar consisting of 3 parts of burnt clay and 2 of lime. Results of tests of this mortar are given in Appendix C. These show that it is equal in strength to 4-to-1 Portland-cement mortar.

Cement-Factory.—It had originally been intended to use Portland cement imported from England, which in 1914 cost LE. 5 per ton delivered at the dam. A total quantity of 200,000 tons of cement was required for the Sennar dam and for the Gebel Aulia dam on the White Nile, and as a result of the great increase in the price of cement, experiments were carried out during the war with a view to find a cheaper mortar. As a result it was decided to build a cement-factory at the Sennar dam and there to produce cement for both works. Experiments showed that local limestone and clay could be burnt largely with charcoal produced from local timber, only a portion of the fuel being imported coke. Shaft kilns were adopted, as being most economical where unskilled labour is plentiful and cheap ; and

Digitized by Google

the necessary machinery was ordered in England at the end of 1918. In spite of delays in delivery due to strikes, amounting in some cases to as much as a whole year, the first kiln was lighted in March, 1921. At first the limestone was brought from Roseires, by barges pushed by stern-wheel steamers during the Nile flood. Suitable limestone was later discovered by Mr. Grabham near Gebel Seggadi, whence it was brought to the works by rail. The limestone is of a crystalline nature and very pure, though extremely hard. Suitable clay is available near the factory. A total of 68,970 tons of cement has been produced at this factory up to 1925; of this, 42,835 tons is red cement and the remainder Portland cement.

Sluice Steelwork.—The main sluices are provided with steel gates running in grooves on Stoney rollers, as at Assuan. These gates are lifted by two overhead cranes which run on rails on the top of the parapets of the sluice dam. Similar gates, worked by hand winches, were put in seven of the regulator-culverts which feed the main Gezira canal. The other seven culverts have been temporarily blocked with concrete. The spillways are closed by horizontal pitch-pine timbers running in angle-section grooves on the upstream face of the dam.

Possible Erosion of Downstream Foundation.—At Assuan it was found that water issuing from the sluices eroded the rock downstream of the dam, and it was necessary to protect this by a masonry apron. The conditions at Sennar are different from those at Assuan, where the water for a large part of the year issues from the sluices under high head and falls upon the rock below the dam, this rock in many places being exposed or only covered by shallow water. At Sennar, on the other hand, the downstream water-level never falls below the sill-level of the main sluices. When it is as low as this, the flow of the river is only about 50 cubic metres per second; and, if necessary, this could be passed through one of the eighty sluices. With minimum level downstream, fifty main sluices have an average depth of 11 metres of water between sill-level and foundation-level at the downstream toe of the dam. Five sluices have a water cushion of 19 metres. When the maximum discharge is passing, the average depth of water downstream is 22 metres, with a minimum of 15 metres, the downstream water-level being above the top of the culverts.

It is hoped that aprons may not be necessary, but in any case it is considered that no such damage could occur as to endanger the dam before they could be built. If they are found to be needed, their construction on the western side would present no difficulties, the channel downstream being shallow enough to be easily blocked

Digitized by Google

with a small temporary "sudd" (earthen dam) and pumped dry. On the east side the sudd required would be larger, but the dam itself would enable it to be made in still water.

Experiments, carried out on a model of the dam to a scale of 1/20, indicate that the action at Sennar should be much less than at Assuan and that the effect of the spillways is much greater than that of the sluices. It will not be necessary to use the spillways except for a very short time at the peak of a high flood. Since 1913, when records of river-levels were first kept at the site of the dam, there has been no occasion when the whole of the discharge of the river could not have been passed through the main sluices, without employing any of the spillways. As a precaution, baffle stones project from the downstream face below the spillways in order to break up the flow of water and throw it away from the foundation rock at the toe.

Construction of the Dam.

There is an island in the middle of the river at the site of the dam, dividing the flow into two channels, of which the eastern was the more important. The general scheme of construction over the river-bed was as follows. The construction of the pierced portion of the dam was commenced over the western channel, the foundations being prepared between sudd coffer-dams. It was cleared also to give a bed-width of 150 metres, the bed-level being graded from R.L. 405 at the upstream end to R.L. 404·50 at the downstream. This was calculated to pass a discharge of 2,000 cubic metres per second without undue afflux and enable the channel to take the whole river flow until the rising flood early in July.

The main (eastern) channel was then dealt with, the sudd coffer-dams, the foundations, and the masonry up to well above the low-river level being completed in one season. This channel of the river is about 300 metres wide, and the maximum depth of water below the lowest summer level of 404 is 13 metres. It was blocked by means of two sudds, upstream and downstream of the site of the proposed masonry dam, between the island and the east bank, the water was pumped out, excavation was carried down to foundation-level in the dry, and the masonry of the dam was built. It was important that this masonry should be completed in one season to such a level that it would be above the next year's low river level, and allow masonry work to be continued without making the sudds again. Work was commenced in the

Digitized by Google

summer of 1923 by the driving, in shallow water at the east of the channel, of 111 interlocking steel sheet piles along the centre-line of the upstream sudd, 95 metres upstream of the axis of the dam, and of 79 piles on the axis of the second sudd, 100 metres downstream (Fig. 3, Plate 2). The piles ranged from 12 feet to 87 feet in length, and were driven by four pile-drivers. The flood that year scoured out all the piles in the upstream sudd, which were afterwards found to be lying on the top of the rock, under the sand of the river-bed, and upstream of where they had been driven. It also removed seven of the piles in the downstream sudd. None of these piles was replaced, an earth sudd on top of the silty sand of the river-bed being relied upon and found adequate.

Between the 10th October, 1923, and the 9th January, 1924, the remaining piles were driven, 237 in the upstream, and 420 in the downstream sudd. The original intention of the contractors was to close the north sudd first, and they had provided piles there fitted with sluices. Owing, however, to the depth of the water, the low level of the surface of the rock, and the swiftness of the stream as the gap in the piles became narrower, great difficulty was found in continuing the work, and there was danger that the sand of the river-bed would be washed away as the gap became smaller. At the south sudd the water was not so deep, and the rock level was higher. The contractors, therefore, decided to close this sudd first, and the piling was advanced from both ends until the gap was 39 metres wide. Bags of earth were thrown on each side of the driven piles to protect them from scour. A large steel barge was then anchored across the gap, and truck loads of stone were thrown from it directly into the river upstream of the barge. The gap was closed by this means on the 17th December, 1923. The maximum head on closing was 1·05 metre. The total discharge of the river was 546 cubic metres per second, of which about two-thirds had been passing along the deep channel through the gap.

The pile-drivers then recommenced work in front of the stone across the gap. An 18-inch suction dredger removed the sand and silt from the top of the rock on the line of the dam and pumped it on both sides of the south sudd. A 24-inch suction dredger at first worked upstream of the south sudd and pumped silt against its south side. Before the gap was closed, this dredger was moved downstream of the two sudds.

The north sudd was closed on the 10th January, 1924, the 18-inch dredger having been removed to the western channel north of the dam, whence it pumped earth through a floating pipe-line to the upstream face of the south sudd. The 24-inch dredger pumped

Digitized by Google

earth from the bed of the river on to the north face of the north sudd. The materials used in these sudds were :—

Decomposed gabbro rock and ironstone conglomerate	cubic metres	53,500
5,425,000 sandbags filled with earth .	,,	72,500
Granite rubble	,,	31,500
Sand and alluvium pumped by dredgers	,,	600,500
Total	,,	758,000

Excavation.—This was generally done by hand labour, the men filling skips, which were lifted by derrick cranes placed at ground-level on each side of the dam. The spoil was usually tipped directly behind the cranes, though in some cases it was removed to a distance in railway-trucks. The same derrick cranes were usually employed for transferring the granite rubble for the masonry from the railway-trucks, in which it arrived from the quarries, to the work. Across the river-channel itself a gantry was constructed immediately upstream of the dam. This carried three lines of rails, that nearest the dam being occupied by small cranes, and the two running-lines behind it being employed for the trains which brought the rubble.

The arrangements for the work in the deep channel are shown in Fig. 3, Plate 2. The progress of excavation was as follows :—

Season 1918–19	cubic metres	177,500
,, 1919–20	,,	15,340
,, 1920–21	,,	131,960
,, 1921–22	,,	38,000
,, 1922–23	,,	85,380
,, 1923–24	,,	200,360
,, 1924–25	,,	22,760
Total	,,	671,300

Progress of Construction.—Work on the masonry was begun in 1921. The western channel of the river was sudded off and pumped dry, and by the middle of April the first portion of sound rock was uncovered. Masonry work was commenced then, and continued until the 20th July in the western channel and until the 20th August on the west solid dam, 518 cubic metres of ashlar and 39,686 cubic metres of rubble masonry being built.

During 1922 masonry work was carried out on the western solid dam and regulator. Work commenced in January, and by the 29th March 393 cubic metres of ashlar and 36,103 cubic metres of rubble masonry had been built. Also 446 cubic metres of concrete were placed. Owing to lack of funds, work was then suspended.

Messrs. S. Pearson and Son, Ltd., took over the works on the

Digitized by Google

1st December, 1922, and masonry work commenced on the 8th December on the west corewall, the west solid and spillway dam, the sluice dam in the western channel, and the east spillway. A total of 92,547 cubic metres of masonry was carried out.

Masonry work was commenced at the beginning of November, 1923, on top of that built the previous season in the east spillway dam, and it was extended eastwards to kilometre 2·360 as the foundations were accepted. Between kilometres 2·091 and 2·112 a small portion of the masonry of the dam had been built to R.L. 403·45 in July, 1923; on top of this a bag sudd had been formed. This allowed excavation to commence early in the portion between kilometres 2·112 and 2·145, and the masonry here was completed to the required levels before it was possible to commence building in the actual river-channel. A subsidiary sudd also had been made at kilometre 1·800; this allowed excavation to the west of this point to proceed ahead of that in the deepest part of the channel up to the work already partly built at kilometre 1·726. Masonry commenced on the 14th January and gradually extended eastwards as the foundations were uncovered.

Whilst the foregoing work at both sides of the deep channel was in progress, the construction of the sudds and the dewatering and excavation down to sound rock in the deep channel itself were being pressed on. Twenty 12-inch centrifugal pumps were mounted on barges. Six of these were driven electrically from a power-station on the east bank of the river; the remainder were worked by semi-Diesel engines on the barges themselves. Four of the latter commenced the dewatering on the 10th January, 1924, when the water-level was 406·24. On the 28th January it had been reduced to 396·63, and the site was practically dry except for a pool from which the pumps drew at the lowest point. The leakage through the sudds, in spite of a maximum head of 24 metres, was easily dealt with by three pumps. The bulk of this water was near kilometre 1·860. It was impossible to make satisfactory sumps in the sand, and the water was pumped out from the top of the sand, whilst excavation was carried out by a grab and men working in the water.

On a length of 20 metres at the toe of the dam the foundations proved to be 5·70 metres below the design level. This involved the cutting back of the downstream slope of the excavation trench, and owing to water issuing from the toe of this slope, there was also always the danger of slips. After excavating through 9 metres of sand and 2 metres of boulders embedded in gravel, a satisfactory sound rock foundation was obtained at this point on the 17th May. After several metres height of masonry had been built, a discharge-

Digitized by Google

pipe from a pump was damaged at night; and, before the pipe could be repaired, the water rose several metres, causing the slope of the excavation to slip and cover the downstream face of the dam with sand to a height of 9 metres above the lowest foundations. Fortunately, the masonry was then at such a height that this had no serious consequences.

Whilst this work was in progress, excavation had been continued at other places in the deep channel. On the 18th March the first portion of the foundations was uncovered at kilometre 2·000 and rapidly extended westwards to kilometre 1·860, while at the same time masonry was extending from the west side eastwards to the same place. The last piece of the foundations was accepted by the 30th May.

The lowest point of these foundations was at R.L. 388, and therefore a height of 22 metres of masonry had to be built in 1 month before the rising flood stopped work early in July. This, and all the required work in the deep channel, was completed by the 5th July. Between the middle of March and the beginning of July 300 masons were employed in two shifts, work proceeding continuously from 5.30 a.m. till 12.30 a.m. Large electric flood lights were attached to the gantry upstream of the dam. Up to 1,000 cubic metres of masonry was built daily. During the season 151,876 cubic metres of masonry was built, of which 100,000 was in the deep channel and 51,876 on the east side. In addition 7,147 cubic metres of ashlar was laid, and 600 cubic metres of concrete placed.

Masonry work for the 1925 season commenced early in November, 1924, comprising the complete east corewall, part of the east solid and spillway dams, the top portion of the sluice dam in the eastern channel, and the sluice dam in the western channel from R.L. 405·25 to the top. Early in the 1924 flood most of the temporary masonry piers of the gantry across the western channel had fallen, therefore in October, 1924, a stone bank was begun across the western channel upstream of the line of the gantry. After this had been closed, earthen sudds were made upstream of it and downstream of the site of the dam; and masonry work began here at the middle of January, 1925. By the beginning of May all bulk masonry work was complete, and by the end of that month the roadway was finished and the sluice-gates were in position.

The total quantities in the dam are—

Rubble masonry	cubic metres	400,489
Ashlar	,,	18,325
Concrete	,,	3,626
Total . . .	,,	422,440

Digitized by Google

Labour.—The whole of the masonry was built by Egyptian masons,

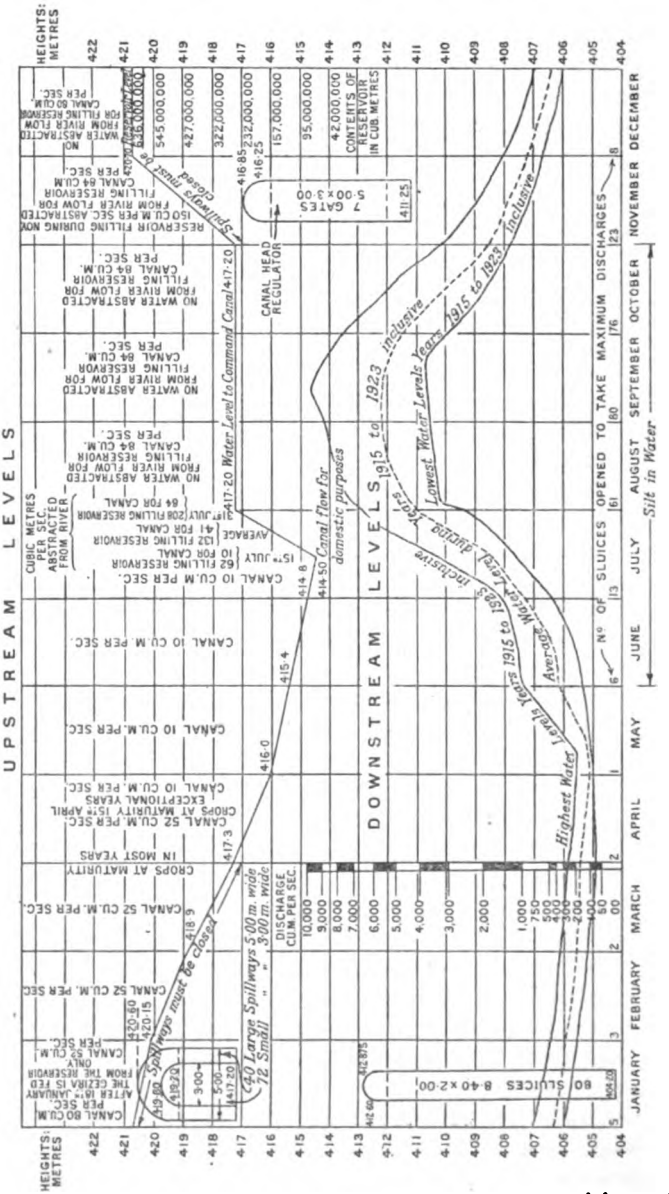


Fig. 6. METHOD OF REGULATION.

who are capable of good work under European supervision. The granite rubble was quarried by Egyptians, and the ashlar cut by

Digitized by Google

Italians. Generally all heavy work in earth and rock excavation, and carrying of rubble, was done by Egyptians. The Sudanese were incapable of heavy manual work, but were employed on miscellaneous things of a light nature. They proved to be in many cases intelligent mechanics, and useful on such work as plate-laying.

Reservoir.

The reservoir contains 636 million cubic metres of water, or allowing for evaporation, 485 millions net. It will be filled during November, when the river is free from silt, and used for irrigation between the middle of January and the middle of April. Between the middle of April and the middle of July only a small quantity will be required for drinking purposes. This reservoir enables the whole of the natural supply of the river to be passed on to Egypt, the Sudan only using water at times when it would otherwise be wasted in the Mediterranean. The maximum reservoir level is 420·70 metres, and its effect will be felt about 160 kilometres up-stream of the dam. The proposed method of regulation of the dam is shown in *Fig. 6.*

Canalization.

The area to be irrigated is 300,000 acres, of which 100,000 acres will be cultivated with cotton each year, and 100,000 acres with other crops. Of the latter about 50,000 acres will be under maize, the staple food of the cultivator, and 50,000 acres under "lubia," a leguminous bean suitable for cattle-fodder. The remaining 100,000 acres will remain fallow. The main canal (Fig. 7, Plate 2) is 114 kilometres in length and runs for 57 kilometres before it reaches the area to be cultivated. At this point its water surface is above ground-level, and the land can be irrigated by gravity. Of the total excavation of 15,300,000 cubic metres, 10,100,000 cubic metres were in the main canal, the remainder comprising branch canals and escapes.

The main canal between the dam and its first regulator at kilometre 57 has the following dimensions :—

Water-slope	7 centimetres per kilometre.
Bed-width	26 metres.
Water-depth	3·40 metres.
Side-slopes	1 to 1.

So far as possible the spoil from the excavation of the canal was deposited on its west side, leaving the east free for subsequent widening.

Method of Excavation.—The soil of the Gezira Plain is a very hard

Digitized by Google

clay, known as black cotton soil (loess). Twenty-four drag-line excavators, which proved to be the most suitable machines, excavated 11,800,000 cubic metres. The remainder—3,500,000 cubic metres—was dug by hand in the small canals. Workmen from Upper Egypt were employed, being usually brought to the Sudan for 6 months at a time in the dry season. The average output per man per day was 3 cubic metres.

The scheme was designed by Sir Murdoch MacDonald, M. Inst. C.E., Adviser to the Egyptian Ministry of Public Works. He also exercised control over the carrying out of the work until his retirement from the Egyptian Government Service in 1921.

The consulting engineers were the late Sir A. L. Webb, M. Inst. C.E., from 1914 until his death in 1921, and Messrs. Coode, Fitzmaurice, Wilson, and Mitchell, from 1922 to the present date.

Colonel L. N. Cooper, M. Inst. C.E., was appointed resident engineer in 1914, followed by Mr. E. W. Buckley from 1914 to 1917. The Author has held that office from 1917 to the present date.

The contractors from 1919 to 1922 were the Sudan Construction Company (Messrs. E. Alessandrini and G. S. Perry, M. Inst. C.E.). From 1922 to the completion Messrs. S. Pearson and Son, Ltd., carried out the work. Their director in charge was Sir Frederick T. Hopkinson, M. Inst. C.E., the agent in charge being Mr. J. W. Gibson.

The sub-contractors for the supply and erection of the sluice steelwork were Messrs. Ransomes and Rapier, Ltd., of Ipswich, their engineer in charge being Mr. J. R. Russell.

The Paper is accompanied by seven sheets of tracings, from some of which Plate 2 and the Figure in the text have been prepared, and by the following Appendixes.

[APPENDIXES

Digitized by Google

APPENDIX A.

Specification for Red Cement.

(1) *Fineness.*—

(a) The residue on a sieve, 180 × 180 = 32,400 meshes per square inch, shall not exceed 14 per cent.

(b) The residue on a sieve 76 × 76 = 5,776 meshes per square inch, shall not exceed 1 per cent.

(2) *Setting-Time.*—

(a) The initial setting-time shall not be less than 60 minutes.

(b) The final setting-time shall not be more than 10 hours.

(3) *Soundness.*—

When tested for soundness by the Le Chatelier method, the expansion shall not exceed 10 millimetres.

(4) *Tensile Tests.*—

(a) Neat red cement briquettes at 7 days shall break at not less than 250 lbs. per square inch of section, and at 28 days, 400 lbs. per square inch of section.

(b) Red cement and sand, when duly mixed in the proportions of 1 part by weight of red cement to 3 parts by weight of sand, shall stand the following tests: at 7 days shall break at not less than 100 lbs.; and at 28 days at not less than 200 lbs. per square inch of section.

The manufacture, testing, manipulation, etc., of red cement shall be throughout in accordance with the British Standard specification, where the conditions of the latter are applicable, but, owing to the climate at Makwar, the conditions relating to temperatures will not be adhered to.

Digitized by Google

APPENDIX B.

AVERAGE TENSILE TESTS OF PORTLAND AND RED CEMENT MADE AT THE SENNAR DAM CEMENT-FACTORY.

Kind of Cement.	Samples from each of the 250-Ton Batches Numbered as below.	Date Made.	Neat Cement. Tensile Strength: Lbs. per Square Inch. Days.		Months.						Cement and Sand in Proportion of 3 Sand to 1 Cement. Tensile Strength: Lbs. per Sq. Inch. Days.		Months.					
			7	28	3	6	9	12	18	24	7	28	3	6	9	12	18	24
Red	R.I-10	Feb.–Apr. 1922	323	547	553	585	632	577	569	605	152	292	359	430	476	471	469	511
	R.II-20	1922	265	439	492	524	528	542	550	573	127	246	308	327	350	381	399	468
	R.92-108	Jan.–Mar. 1924	304	481	512	535	577	605	No further briquettes		129	273	335	364	391	410	No further briquettes	
Portland	P.18-21	Jan.–Feb. 1922	585	725	722	786	780	748	755	875	246	333	360	432	448	454	465	485
	P.22-43	1922-23	517	625	643	678	666	676	757	No further briquettes	216	308	319	369	400	414	448	No further briquettes
	P.58-74	Dec. 1923 Feb. 1924	615	743	688	677	777	828	No further briquettes		232	324	356	364	416	438	No further briquettes	

Note.—Standard Leighton Buzzard sand was used for the 7- and 28-day tests.

For the 3 months and longer tests local sand was employed.

For some of the long tests (3 to 24 months) samples were taken from each 1,000 tons only, not from each 250 tons.

Digitized by Google

APPENDIX C.

Tensile tests of mortars, including Lime and Homra.

Particulars.	Tensile Strength: Lbs. Per Square Inch.									
	Days. 7	Month. 1	Months. 2	Months. 3	Months. 4	Months. 5	Months. 6	Months. 9	Months. 12	Months. 15
Lime and Homra 2 to 3 mixed in a mortar mill	..	168	200	218	250	253	305	238	307	308
Lime and Homra 2 to 3 mixed by hand on a table	..	100	118	168	175	170	209	179	240	225
Portland cement	512	580	655	725	620	775	777	774	808	732
Red cement	353	517	548	550	635	575	594	616	631	598
Portland and sand 1 to 4	60	120	138	155	168	213	218	228	245	241
Portland and sand 1 to 3	100	185	228	240	255	330	307	349	359	379
Red cement and sand 1 to 4	55	120	158	185	163	216	233	236	235	244
Red cement and sand 1 to 3	75	165	208	226	215	245	265	286	314	337

Note.—Ordinary local unsieved sand was used in all the sand tests. This sand is the same as was actually employed on the dam.

The Portland and red cement used were some of the first made at the factory.

The lime and homra mortar is about equal in tensile strength to the Portland and sand 1 to 4 and red cement and sand 1 to 4. The latter was actually employed in the bulk of the work on the dam.

Digitized by Google

Discussion.

Sir Murdoch MacDonald.

Sir MURDOCH MACDONALD, K.C.M.G., M.P., remarked that the Author deserved very great credit for the Paper and for the valuable work done by him at Sennar, and he regretted that he was not able to be present at the meeting. While he (Sir Murdoch) was not in a position to criticize the design of work for which he was responsible, it might be of interest if he explained its functions. The construction of the Sennar dam was in reality no recent idea, and it was another exemplification of the fact that there was nothing new under the sun. The dam under discussion was first proposed, about 1845, by a German savant, who described his suggestion in a book on his travels on the Blue Nile, and strongly recommended that the plain of the Gezira should be irrigated, and a work built to enable this to be done. Years passed, however, and nothing was done, and Sir Murdoch doubted if anybody in recent years knew much about the proposal. His own attention had been drawn to it by the late Sir Alexander Baird, who lived in Egypt for a great part of his life and took a keen interest in all such matters, and who had the book referred to in his library. Long afterwards, about 1904, the late Sir William Garstin suggested —almost certainly without being aware of the previous suggestion— that a dam should be placed across the Blue Nile to take advantage of the vast Gezira plain. The intention was that that plain should be utilized owing to its capabilities for growing wheat. It was found, however, that wheat took too much out of the soil, and that in any case the cost of transport to the coast for sale in the European markets, etc., would make it an impracticable scheme. He believed that Lord Lovat had been the first to recognize that the plain would be an excellent place for cotton-growing. His Lordship suggested this to a Mr. MacGillivray, who made the brilliant proposal that, as the climate of the plain was too hot for cotton in the summer time, it might be grown there in the winter instead. The scheme, therefore, was taken up with that main object. He (Sir Murdoch) considered that it would be a very desirable state of affairs if all the cotton that England required could be grown in the British Empire. There were two main kinds of cotton, the long-staple and the short-staple. The former was almost entirely an irrigation-grown cotton, and its staple usually

Digitized by Google

exceeded $1\frac{3}{16}$ inch in length, whereas the short-staple was generally less than that. The total world production of cotton amounted to about 11,000 million pounds annually. Cotton was usually reckoned in bales, but, as most countries exported bales of different weight, he thought it better to give the figures in pounds. Of that total the long-staple cotton only amounted to about 1,000 million pounds, and the Gezira project was intended to increase that quantity—which was only 9 per cent. of the total. Curiously enough, Egypt produced 600 to 700 million pounds of long-staple cotton; in other words, the vast bulk of long-staple cotton was produced in territory which was in close diplomatic contact with the British Empire. Long-staple cotton could only be grown in the Sudan by lifting the water of the Blue Nile on to the Gezira plain. Egypt had no great love for a scheme of that sort and deprecated the proposal for two reasons; firstly it might take from the river water which they required for themselves, and secondly, it was intended to produce the kind of cotton of which they held a virtual monopoly. The scheme as envisaged by the Author comprised 300,000 acres, of which 100,000 acres would be planted with cotton each year; but beyond that there were vast possibilities. The 100,000 acres would only produce 40 million pounds of long staple cotton a year—an addition of 4 per cent. to the total world production; but there was a great area which might be irrigated if more water were provided. The larger hatched area in Fig. 1, Plate 2, was 3 million acres in extent, and the smaller 300,000, which was actually cultivated now. The whole 3 million acres would eventually be utilized if sufficient water were provided from other sources higher up the Blue Nile. There was an extremely high rainfall at Lake Tsana (or Tana) at the head-waters of the Blue Nile, and it was possible there to control 3,000 million tons of water. It was further practicable to lower the outlet of the lake, which would add another 4,000 million tons. The largest reservoir in the world at the present time, which was in America, exceeded 3,000 million tons in capacity. He thought it would be possible to build very cheaply at Tsana a reservoir capable of storing a total of 7,000 million tons. With that water it should be possible to cultivate a great part, if not the whole, of the 3 million acres in the Gezira and to increase the quantity of long-staple cotton, not by 4 per cent. but by 40 per cent., representing 400 million pounds of cotton per annum. The scheme, therefore, as envisaged by the Author, while undoubtedly a huge one, had vastly greater potentialities lying behind it. However, long-staple cotton was not the only kind that this country required. About 4,000 million pounds of short-staple

Sir Murdoch MacDonald

Digitized by Google

Sir Murdoch MacDonald.

cotton, which cost only half as much as long-staple per pound, were imported annually, to be made up in the Manchester area. The growth of short-staple cotton, therefore, should be encouraged also. It was conceivable that at some future time America might discourage the exportation of cotton by means of taxation or duties; and it would then be necessary to find a fresh field where short-staple cotton could be grown. Those who had helped to develop the Gezira area had done excellent work in safeguarding the best interests of the British Empire. He was very glad to have been, to some little extent, associated with the matter. The development of the scheme had been due in large measure to the late Sir William Garstin, though the practical proposal was Lord Lovat's and Mr. MacGillivray's. Mr. Dupuis, who was asked by Sir William to consider the matter, had gone very carefully into the questions whether a dam should be built near Sennar or farther up the river, and whether the quantity of water was sufficient for the area or not. He was sure that Sir William Garstin, had he been alive and present that evening, would have been glad to know that the Paper had been read and that the work with which he had been associated had been brought to a successful conclusion.

Mr. Vaughan-Lee.

Mr. A. G. VAUGHAN-LEE observed that Sir Murdoch MacDonald would be glad to hear that rain-grown cotton was now grown in the Sudan; he had been told that the output of the native rain-grown cotton, which was nearly all short-staple cotton, would in the near future probably equal that of the irrigated long-staple cotton. He would like to correct the misapprehension that the Sennar dam was robbing Egypt of water, as there was a very grave misunderstanding on that subject. From the middle of March until the middle of August no water from the Nile passed into the Mediterranean, as temporary earth dams or sudds were run across the Damietta and Rosetta mouths. The flood came down in August to Lower Egypt and washed away the sudds. The water took about a month, or a little longer, to get from Sennar to the delta, so that water taken from the Blue Nile at Sennar in the middle of July, if it had been left, would have reached the Mediterranean about the time that the sudds broke; any water taken from the Blue Nile for impounding in the reservoir at Sennar in the latter part of July would otherwise have run to waste in the Mediterranean, and Egypt would not get the benefit. *Fig. 6* (p. 94) showed that the water for impounding was abstracted from the river only in July and in November. There was, therefore, no question at all of Egypt being robbed of any water. The reservoir had been filled this year for the first time, and when he was there in January the

Digitized by Google

reservoir was full. The main canal would take a maximum flow of about 87 cubic metres per second, but at the present time only about 37 cubic metres per second was required for irrigation. Consequently there was an immense surplus of water in the reservoir, and Egypt was about to get the benefit of that water, which was being let down in flushes at intervals of about a fortnight for replenishing the Assuan reservoir, which was now being let out. During the present year Egypt would benefit by 350 to 400 million cubic metres of surplus water which was not required by the Sudan. The original intention had been never to let the level of the Sennar reservoir fall below + 413, but the Sudan Government irrigation advisers now intended to let out the reservoir to the bottom. Egypt was very short of water in the summer months, and she was now getting this additional water, which would tide her over until the Gebel Aulia dam was constructed. The reservoir formed by that new dam would be of about the same capacity as the Assuan reservoir after allowing for losses. The dam at Sennar, as the Author stated, was crossed by the Sudan Government Railway, and this was a very useful adjunct, because it was intended that the railway should be extended via Kassala to Port Sudan. That meant that there would be practically a double line of railway from Khartoum to Port Sudan. The railways at present were becoming congested, and in view of the cotton traffic from the Gezira, the dam itself formed a much needed bridge. Sir Murdoch MacDonald had alluded to the possibility of damming Lake Tsana; an interesting report had been published[1] recently by the Egyptian Ministry of Public Works dealing with the question of the site of that dam. A further report just published[2] dealt with the possibility of building a dam across the outlet of Lake Albert and regulating the supply down the White Nile. Those works were bound to come in future. When the water was raised in the Sennar reservoir, a certain number of small leaks were observed in the masonry of the dam, but considering the length of the work he thought there were very few. In all works of that kind there were always leaks, and he drew attention to the matter because he thought the information would be useful to those who dealt with such works in the future. It was possible in this case to measure the leakage passing through the long wings on each side of the river. At one time on the east bank the seepage through the rubble masonry was about 255 cubic

Mr. Vaughan-Lee.

[1] G. W. Grabham and R. P. Black, "Report of the Mission to Lake Tana, 1920-1921." Cairo, 1925.

[2] H. E. Hurst, "The Lake Plateau Basin of the Nile." Cairo. 1925.

Digitized by Google

Mr. Vaughan-Lee.

feet per minute, and that was subsequently reduced to about 42 cubic feet per minute. On the other hand, the seepage on the west bank was only about 33 cubic feet per minute, and that had been reduced now to 9 cubic feet per minute—practically negligible on a dam of that length, considering that it was built of rubble masonry. The difficulty of getting rubble masonry watertight was in practice very great: owing to the very large number of masons at work, it was difficult to supervise every one, and stones were no doubt sometimes placed without the necessary amount of mortar. A considerable number of leaks had been stanched effectively by depositing over the upstream side of the dam ashes and fine soil, but the best material had proved to be powdered decomposed rock out of the foundations. Another point in connection with the dam was the necessity for aprons on the downstream side. Sir Murdoch MacDonald in his original design provided for aprons, but on account of the preliminary expense and other considerations the aprons had been omitted, as they were not deemed necessary in the first instance. The downstream side of the Sennar dam was not like the Assuan dam, because the water at Sennar discharged through the sluices into a water cushion, as described in the Paper. Very probably aprons would be required at Sennar in the west channel, because there the foundations were high and damage would no doubt occur if great care were not taken n regulating. In the east channel, where there was a great depth of water, he did not think aprons would ever be required, provided discretion was used in manipulating the sluice-gates. There had been one flood since the dam was built, and no damage had been caused to the foundations. Examination by divers and very careful soundings had shown that only soft soil at the top of the decomposed rock had been washed away. With regard to criticism of the design, the sill levels of the main sluices of the dam were always below the water-level in the river, and there was no means of getting at the bottom of the gates or of clearing them, except by damming the water right out, which was very expensive. In works of that sort there ought to be some means of getting at the bottom of the gates if possible. There was a curtain at Assuan and a similar curtain had been provided at Sennar, but he was afraid it would not be possible to use it at Sennar, because the ground on the upstream side of the dam was now practically flush with the bottom of the sluices, and there would be no room for the drum of the curtain to unroll down below the bottom of the sill. An interesting experiment had been started in connection with the sluices, as on ten of the main gates the stanching-bars were of rustless steel and on

Digitized by Google

the remainder of the gates they were of ordinary steel. In a few years' time he thought valuable information would be obtained as to the behaviour of this rustless steel under practical working conditions. The Paper dealt mainly with the dam, but he wished to allude to the canalization portion of the work, which was just as big a job as the dam—in fact, in his opinion, it was a more complicated and harder task, when the large area that had to be covered and the organization that had to be developed to carry stores and food to the men over that area were taken into consideration. To put it roughly, the main canal was about as long as the distance from London to Bedford, about as wide as Regent Street, and would float a Dover–Calais boat. The branch canals comprised 900 kilometres of channels of various sizes and types. The canalization and the dam had had to be finished on the 15th July, 1925, otherwise the Sudan Government would have lost a whole year's cotton crop. The dam had been completed easily within the contract time, but it had been a tremendous rush to get the canalization finished, and the contractors deserved great credit for it. The main canal had been filled from the dam, the water having been allowed to trickle down. It had taken about 2 days to travel the 57 kilometres to the first regulator. The first portion had travelled fairly slowly, because the water had not risen quickly enough in the reservoir to get a head on the canal, but after a certain head had been obtained the water went down at the average rate of about 1 kilometre in 43 minutes. The whole of the canals below the main regulator had been filled from the pumping-stations owned by the Sudan Plantations Syndicate. He could not conclude without alluding to the energetic way in which Messrs. Pearson & Son had carried out the job. Nearly all the preliminary organization had been done by the original contractors, Messrs. Alessandrini and G. S. Perry; but when Messrs. Pearson took over they had a big task before them. Thorough organization was the most important factor contributing to their success; and the figures given for the output of masonry in the dam and the excavation in the canals showed what great efforts had been made to carry out the works in good time.

Mr. Vaughan-Lee.

Mr. Maurice F.-G. Wilson thought that the most remarkable feature of the work was the way in which the contractors had carried it out. They had had a stupendous task, and the organization for both the dam and the canalization had been extraordinarily good. The foundations had proved to be somewhat higher than expected, which had been very satisfactory. The usual experience was to find the foundations had to be deeper than anticipated, resulting in a great deal of trouble. Red cement appeared to be

Mr. M. F.-G. Wilson.

Digitized by Google

Mr. M. F.-G. Wilson.

ordinary Portland cement mixed with burnt clay; similar mixtures were used at the Mediterranean ports. The strength, although considerably less than that of Portland cement in the earlier stages, appeared to approach that of Portland cement in time. A new cement, known as Portland blast-furnace cement, had been made in the last few years, which was a very similar mixture; slag was mixed with the cement, instead of burnt brick or clay, and its action was very much the same. It was claimed that it tended to make the concrete much more watertight and impervious. With regard to the discharge of the river and the abstraction of water, he had been struck by the very small quantity of water that really was abstracted from the river, as shown by *Fig. 6*. From July to November, taking round figures, only about 100 cubic metres per second was abstracted to replenish the reservoir, and about 80 cubic metres per second for the canals. During that time the river discharge was about 4,000 cubic metres per second. He was much indebted to Sir Murdoch MacDonald for the interesting account he had given of the early history of the scheme.

Dr. Lowe-Brown.

Dr. W. L. LOWE-BROWN congratulated the Author on the Paper, which he thought was a model of condensation, particularly as to the information given in *Fig. 6*. It was almost inevitable in a work of the kind described that some of those connected with it should not see the end of it. The late Sir Maurice Fitzmaurice had been associated with the work as consulting engineer, especially during the time when the deep foundations were being put in, and therefore it was not out of place to quote a remark made about him many years before by Sir William Willcocks, in connection with the foundations at Assuan. Sir William stated[1] that Mr. Fitzmaurice, as he then was, had "allowed no questions of expediency or expenditure to interfere with his resolve to reach such rock as he considered suitable." The design of the Sennar dam was due to Sir Murdoch MacDonald, who deserved the greatest credit. The difficulty of building a dam on the Nile was not to build one which would stand when the reservoir was full, but to build one which would stand with 15,000 tons of water a second passing through it. To a superficial observer the Sennar dam might seem to be a copy of the Assuan dam, but they were essentially different. The Assuan dam formed a reservoir which passed on water to Asyut where the irrigation was done; the structure at Sennar was a dam, reservoir, regulator, and railway bridge, and he thought that ought to be taken into account in comparing costs. No responsible engineer

[1] *The Egyptian Gazette*, October 2nd, 1901.

Digitized by Google

would have designed the Sennar dam without the experience of Assuan. Assuan was a great pioneer work, which would not have been undertaken if Sir Benjamin Baker had not agreed to assume the responsibility. There had been two unknown factors about the Assuan dam. The first was whether the sluice-gates could be opened and closed with a great pressure against them, and the other was the effect of increase of velocity on the foundations. The maximum head under which the sluices could be operated had not been known, so, to make quite sure, the engineers built the sluices at different levels, so that, whatever the level of the water in the reservoir, a set of sluices was always available at a convenient level to discharge the water. Sir Wilfrid Stokes had designed a gate which could be opened under almost any pressure, but that had not been available when the Assuan dam was built. Sir Murdoch MacDonald had taken advantage of it at Sennar. Sir Murdoch had solved the second problem by the use of aprons, but the solution had only been found after an anxious period of observation and experiment. He had been with Sir Murdoch for about 1½ year after the dam was finished, and he knew that he had a very anxious time until the matter was solved. Sir Murdoch had studied not only that point but also a great many other questions in connection with the work at Assuan, which had been dealt with in the Institution Proceedings in Papers[1] written by him and by other Authors. Those Papers taught lessons learned from that pioneer work, and Sennar was really a concrete expression of the lessons which Sir Murdoch had learned. The maximum discharge at Sennar was roughly the same as at Assuan, but the river at Assuan was 1,800 metres wide, whereas at Sennar it was only 500 metres. If the sluices had been arranged, as at Assuan, in steps, one hundred and forty would have been necessary, occupying more than 1,000 metres in length, but that room was not available at Sennar. By putting them all at one level, 100 sluices would have served, but there was not room for even that number, so the sluices had to be placed slightly lower, relative to low water, and to be made 8·40 metres high as against 7·00 metres; in that way eighty were able to take the flow. Just as it had been necessary at Assuan to have a very competent engineer on the spot to keep a careful watch, especially for the first few years, to see the effect of the scour, so at Sennar it would be necessary to do the same, and he hoped the Sudan Government would appoint

Dr. Lowe-Brown.

[1] Minutes of Proceedings Inst. C.E., vol. cxciv (1913), p. 249; vol. ccxii 1921), p. 228; vol. ccxviii (1924), pp. 72 and 113.

Digitized by Google

Dr Lowe-Brown. an able engineer to study the results carefully. He hoped that they would find one who would take as much interest in the work as Sir Murdoch MacDonald had done at Assuan. He believed that the result of those observations would be to confirm the opinion of a previous speaker that aprons would be found necessary, at least in front of some of the sluices. The climate at Assuan was bad enough, but at Sennar it was much worse, because there was a regular rainy season with its accompanying malaria; and those who had carried out the work deserved great credit—both engineers and contractors. The general way in which the work had been done was much the same as at Assuan, but the narrower river-channel had made the task more difficult for the contractor, as it made it more difficult for the engineer, although this was attenuated by the very much smaller flow of water in the working-season, making possible the use of dredgers and other floating plant, without which it would have been difficult to complete the sudds in the time available. The use of steel piles was an innovation, but it did not appear to have been entirely successful, and he would like to ask the Author whether in his opinion it was justified. The use of a steel barge to help in closing the gap in the sudd was a great idea, and, he was sure, very satisfactory. At Assuan they did tip a railway-wagon into the gap, but that was not big enough. The method of stopping springs was an improvement and was, he was sure, also very satisfactory. The irrigation was on quite a modern system. Instead of allowing the land to become over-irrigated and building drainage-canals to reduce the damage, the engineers spread the canals over as much land as they could possibly irrigate, and in that way made it everybody's business to economize water. A certain amount of lime mortar had been used at Assuan, and during the first year he was there he was engaged in making tests upon it. When cement was expensive great economy could sometimes be effected by using lime and burnt clay, which, as shown by the tests in the Paper, made very good mortar. Since those days he had used a similar mortar in the Argentine, but instead of using 2 parts of lime and 3 of burnt clay, he used 1 of lime, 1 of burnt clay, and 2 of sand, and he believed that the mortar had greater compressive strength, although it was perhaps a little weaker in tension. He thought that the use of red cement seemed justified, both chemically and economically, and its colour might be of great assistance in determining whether the mortar had been properly proportioned and mixed.

Mr J. S. Wilson. Mr. J. S. WILSON, who remarked that, while he was assisting the late Sir Benjamin Baker, the stresses in the Assuan dam as

Digitized by Google

built and in the proposed raised dam were carefully considered, drew attention to an interesting comparison between the section of the Sennar dam and that of the original Assuan dam. In the section DD, Figs. 4, Plate 2, the point where the upward continuation of the 1-to-1·5 downstream batter line cut the corresponding line of the upper vertical part of the downstream face, was about 6½ metres below the crest. The Assuan dam as built was of the same section, except that the vertical distance corresponding to that just mentioned was 4 metres. It was proposed to raise the dam by adding a height of 5 metres. That would have resulted in the upper rectangular block being 9 metres high, as compared with the 6½ metres at Sennar. When the Assuan dam was raised, it was, of course, made thicker, to keep the stress conditions within satisfactory limits. If, however, the proposal had been to raise the crest 2½ metres, making the upper rectangular block 6½ metres as at Sennar, the inference was that Sir Murdoch MacDonald would have passed that, because in the Sennar dam he had taken what was practically the original Assuan section and had added 2½ metres to the top. The original International Commission which considered the first design of the Assuan dam decided that the stress should not exceed 5 kilograms per square centimetre (4·57 tons per square foot), and in the raised Assuan dam the stress was kept below that figure. Considering that a stress of but 4½ tons per square foot was imposed on granite which would stand 1,000 tons per square foot, and on mortar which would stand 100 tons per square foot, it was reasonable to endeavour to utilize the material to better advantage, and Sir Murdoch had allowed 6·43 tons per square foot. The stress conditions in the upstream face were of interest. The International Commission on the Assuan dam allowed no tension there. What were the stresses on the upstream face of the Sennar dam? Had the condition been followed that the pressure on the masonry at the upstream side of the foundations should at least equal the hydrostatic pressure of the water? In the report on the Bouzey dam disaster, it was pointed out that, if the stress in the masonry at the upstream face were kept in excess of the hydrostatic pressure at every point, any incipient crack would not tend to be enlarged by the water getting in. That was an important consideration, but it generally involved keeping the maximum stress low. With regard to the criticism made by Mr. Vaughan-Lee as to the difficulty of getting the curtain down over a sluice owing to the presence of silt, the suggestion was made that if the sill of the sluice had been put higher, it would have been clear of the silt. Mr. Wilson asked why the silt was level with the sill at present—he imagined it accumulated

Mr. J. S. Wilson.

Digitized by Google

Mr. J. S. Wilson. up to that level. As to the percolation that had been mentioned, the passage of water through a mass of rubble masonry of the thickness of the dam must depend on the masonry, not on the design. Another interesting point from the design aspect concerned temperature effects. In the Assuan dam there were cracks caused by the temperature changes. Had any cracks formed in the Sennar dam or had artificial cracking places been provided? Referring to the part downstream elevation, Figs. 4, Plate 2, the impression was that, since the depth of masonry over the sluices in the spillway portions was rather small, there would be a liability of cracks occurring.

The Author. The AUTHOR, in reply, pointed out that the greater part of the leakage mentioned by Mr. Vaughan-Lee came through the masonry of the narrow corewalls at the two ends of the dam. That leakage had been anticipated, and was one of the reasons for providing the rubble filling at the backs of the walls, as shown on the cross sections F F and H H, Figs. 4, Plate 2. At intervals of about 100 metres cross drains of rubble, not shown on the drawings, led away the seepage under the earth embankment behind. Through the masonry of the dam proper the leakage was small, with the exception of about two-thirds of the short length of 137 metres of solid dam on the east side. That portion of the dam had been built in 1925, only a few months before the water was raised upstream in July of that year. The percolation through it was included in the figures given by Mr. Vaughan-Lee. At other places on the dam the leakage was negligible. In particular this was so at the solid dam built in 1923 on the west side. He was unable to state definitely the reason for this: he did not consider that it was because of worse workmanship on the east than the west; possibly it was due to the fact that between 1923 and 1925 lime from the cement in the mortar became free and tended to fill the interstices in it, making it watertight. Whilst agreeing as to the difficulty of supervising such a large number of masons, and not claiming that every stone was bedded in the correct quantity of mortar, he drew attention to the fact that it was only a 4-to-1 mixture in the bulk of the masonry. He did not think that such mortar could be expected to be absolutely watertight, even if the workmanship of the native masons had been perfect. In addition to the stanching materials thrown on the upstream face, which had proved very effective as stated, the upstream pointing had been examined, and repaired where necessary, while the dam was empty in the 1926 summer, so as to prevent water from reaching the mortar in the hearting. The superficial area of wall between the highest water

Digitized by Google

The Author.

and ground-level, through which the leakage mentioned percolated, was about 2,800 square metres on the east and 1,000 on the west. On the whole, judging from photographs, he did not consider that the Sennar dam compared unfavourably with the original Assuan dam, which had been built with a similar mortar, except that the cement was Portland and not red cement. So far there were no contraction cracks in the dam proper. In the corewalls there were ten, five at each end, but of these only two were measurable. None had appeared between the sluices and spillways at the places mentioned by Mr. J. S. Wilson. No artificial cracking places had been provided at any part of the dam. With regard to the erosive action of the water downstream of the dam, it appeared from the latest soundings that it had no power to move material 12 metres below the sill-level of the sluices, that was at R.L. 392, which was the present level of the bed of the river in the neighbourhood of sluice No. 45, where the foundations were 8 metres lower. Whilst the permanent water-cushion downstream of the dam was proving very useful as a protection to the foundations, which did not appear to have been affected in any way, it rendered it very difficult, except by making sudds at great expense, or employing divers, to do anything to the downstream face below the sill-level of 404, which was the lowest level to which the water fell, even when the whole river-discharge was stopped. This was unlike the conditions at Assuan, where the downstream face of almost the whole dam could be dried by directing the river through one or two sets of sluices in one of the old channels. At a few places at Sennar some erosion of the downstream face of the dam had taken place: face stones had been worn smooth and a few dislodged, and pointing also had been eaten away. Repairs had been carried out by diver. The damage appeared to have been due to the churning of pieces of hard granite rubble, from the debris left below the dam after the 1924 work. It was impracticable in the time then available to clear the whole of the downstream material, from which came the stones that caused the damage. It was possible to reduce the water-level to about 2 metres above the sills of the sluices by completely opening the dam when the discharge of the river was small. It was, no doubt, a disadvantage that the sills were so low; but, as pointed out by Dr. Lowe-Brown, it was difficult to obtain the necessary waterway, owing to the narrowness of the river. Also, as Mr. J. S. Wilson had observed, the higher the sills of the sluices were placed, the higher would the silt be liable to settle upstream. Soundings taken recently along the upstream face showed that it would be impossible to use the

Digitized by Google

The Author. curtain at most of the sluices in the western channel, that was from Nos. 1 to 27, but in the eastern channel the level of the silt upstream was not so high that it would interfere with its use. Whilst quite agreeing with Mr. Vaughan-Lee about the difficulty of the work on the canalization, the Author thought that his remarks might unintentionally create a wrong impression about the work on the dam. It was quite true that, once the building had been carried out across the deep channel in 1924, it was easily completed within the contract time; but the whole crux of the work had been to get that deep channel done in that one season. With regard to Dr. Lowe-Brown's query, it was difficult to say whether the use of steel sheet piles had been justified or not. They were an innovation by Messrs. S. Pearson & Son, and had not been included in the original design for the temporary works made by Mr. Alessandrini. It was understood that the principal reason for them was the fear of water travelling through possible gravel-seams in the material of the bed overlying the rock. Their advantages were that they should have reduced the cost of pumping, and, indeed, have ensured that the quantity of water was not unmanageable. Their disadvantage was that it was necessary that they should reach the top of the decomposed gabbro rock. The dam was built on a longitudinal ridge, and therefore the two sudds had had to be brought closer to the dam in order that the piles should reach this rock. This had cramped the room available for the actual building of the permanent dam. Several of the sumps for the pumps had had to be made on the site of the dam and moved about as the masonry work progressed. Also the piles had taken a long time to drive, and possibly had delayed the progress which otherwise would have been made in constructing the sudds. The difficulties of keeping them in true alignment in the swift-flowing river had been great, and, in fact, there had been many gaps, so that they had not really formed a continuous watertight cut-off. Also, as mentioned in the Paper, and as shown in Fig. 3, Plate 2, a large number were washed out during the 1923 flood, and consequently a considerable length of the south sudd was without them. As it was impossible to say exactly what would have happened if they had not been used at all, it was difficult to give a definite opinion as to their advisability. On the whole, looking back after the work, the Author thought it would have been better not to have had them. He wished to make it quite clear, however, that such was his opinion after the work. When they were proposed by the contractors he raised no objection, and, in fact, welcomed them as an added precaution.

Digitized by Google

The Author. With regard to Mr. J. S. Wilson's query as to whether the regulation had been adopted that the masonry pressure on the face should exceed the hydrostatic pressure at any point, Dr. Phillips, who had dealt with this part of the original design, had written that the masonry pressure, neglecting uplift, at the upstream toe of the dam at R.L. 387 metres in the pierced section, when the upstream level of the water was 420·70 and the downstream was dry, came to 2·31 kilograms per square centimetre (2·16 tons per square foot), whereas the water-pressure was 3·37 kilograms per square centimetre (3·08 tons per square foot), that was, the masonry-pressure was roughly two-thirds of the water-pressure. That was what Dr. Phillips had expected, since in allowing for uplift he had allowed for water-pressure starting from full head upstream and falling to full head downstream, and acting over two-thirds of the area of the horizontal section. As the resultant pressure came a little inside the middle third, the masonry-pressure was a little more than two-thirds of the water-pressure.

Correspondence.

Mr. Dare. Mr. H. H. DARE observed that, taking into account the climatic conditions, the difficulties of unwatering, and the limited period available each year for working in the river-channel, the successful completion of this great work in a reasonable time was a matter for congratulation to all concerned. The proportion of mortar in the Sennar dam, 40 per cent., corresponded with that in the original Assuan dam, in which it was stated[1] to have "varied between 35 per cent. and 42 per cent." Did the size of the granite hearting stone used at Sennar correspond also with that used at Assuan? Even allowing for the great increase in the cost of all construction work since 1902, the comparison of the cost per acre-foot of water stored was somewhat striking, namely:—

	Capacity: acre-feet.	Cost per acre-foot.
Assuan Dam (original height)[2]	863,453	£2·7
Sennar Dam	515,612	£11·1

The cost, per acre-foot of water stored, of four large irrigation

[1] Minutes of Proceedings Inst. C.E., vol. clii, p. 89.
[2] *Ibid.*, p. 104.

Digitized by Google

Mr. Dare. dams in New South Wales, with which Mr. Dare was connected, was estimated as :—

	Progress	Capacity: acre-feet.	Cost per acre foot.
No. 1.	Practically completed	771,641	£2·2
No. 2.	In progress	2,000,000	£2·3
No. 3.	Preliminary designs prepared . .	273,694	£4·9
No. 4.	„ „ „ . .	520,000	£4·6

In the case of No. 2 the original proposal had been for a dam to store 1,100,000 acre-feet of water; and the structure, which was partly an embankment with a concrete core, and partly a concrete overfall section, had been commenced upon that basis; but in view of later developments the question of increasing the capacity to the larger figure given above was now receiving consideration. Nos. 1, 3, and 4 were concrete structures. In each case a flood of considerable magnitude had to be provided for, but as no unusual amount of silt was carried, the provision of sluices was not necessary to anything like the same extent as in the Nile dams. This factor had, no doubt, an important bearing upon the cost, but on the other hand, the lowest wage paid to workmen engaged upon the construction of dams in New South Wales was, at the present time, 17*s.* 0*d.* per day of 8 hours. No adequate comparison could, of course, be made of the cost of works carried out under such different conditions, but it would be of interest to know whether the full cost of the Sennar dam, as well as that of the main and reticulation channels, was to be charged to the irrigation area, and if so, what were the charges per acre per annum for rent (or purchase) of land, and for the supply of water for irrigation.

Dr. Hurst. Dr. H. E. HURST congratulated the Author, the contractors, and the staff employed, on having brought to a successful conclusion the work on the Sennar dam and the canalization of the Sudan Gezira, the difficulties of which could only be properly appreciated by those familiar with the conditions. It might, however, be mentioned that during three of the principal working-months the average maximum temperature was 106° F., and the mean temperature 88° F. He had been consulted when the designs were being made as to what the discharge of the sluices was likely to be. The only information then available was from Assuan, where the sluices were of similar design, but where the conditions of upstream and downstream level were different. At that time it was not possible to make a detailed forecast of the discharge of the Sennar sluices under all conditions, but the information sufficed to decide how many sluices were necessary to carry the maximum discharge. Since that time further work had been done on the discharge of the

Digitized by Google

Assuan sluices,[1] and in particular it had been shown that a model could be used to determine the discharge of a large sluice. At the Author's request a model of a Sennar sluice had been constructed, and its discharge had been measured over a wide range of conditions. This model was of brass, and to a scale of 1/50. The general results showed that there were two modes of discharge, with a region of transition between them. In one the discharge depended only on the upstream level and was the same as the free discharge into air. It was represented by $Q = cA\sqrt{2g(H - F)}$, where Q was the discharge, c a constant, A the area of sluice-opening, H the level upstream above the sill of the sluice, and F a constant, for a particular opening, which, except in the case of a fully-open sluice, was about 0·8 times the height of the opening. This mode of flow occurred with the lower downstream levels, but as the downstream level was raised, there came a point, depending on the upstream level and the opening, when the discharge was affected by the downstream level. The formula then became $Q = cA\sqrt{2g(H - h)}$, where h was the downstream level above the sill. At first c varied with the downstream level. This was the transition region. Ultimately, as the downstream level rose, c became steady and usually had the same value as in the first equation. The second mode of flow was then properly established. The model experiments had been used to predict the discharge of the full-scale sluice by means of the relation $Q = n^{2\cdot5}q$, where Q was the discharge of the actual sluice, q the discharge of its model, and n the ratio of the linear dimensions of sluice and model. The regulation of the Sennar reservoir was being based upon these results, and so far there had been good agreement between the discharge of the Blue Nile as determined from the sluices, and as measured by current-meters downstream of the dam. Cases could probably be devised in which a sluice and its model would behave differently, but it was clear that in general models would give, cheaply and quickly, results which could only be obtained otherwise by a considerable expenditure of time and money. With regard to the calculations of uplift due to the penetration of water into the masonry, which were mentioned in the Paper, he would like to suggest that for future reference the assumptions upon which these were based should be recorded.

Dr. Hurst.

Mr. J. M. Lacey asked whether it was proposed to grow the crops in rotation on the area of 300,000 acres which was being irrigated at present. The soil was stated to be a very hard clay

Mr. Lacey.

[1] Minutes of Proceedings Inst. C. E., vol. ccxviii (1924), pp. 72 and 113.

Digitized by Google

Mr. Lacey. known as black cotton soil (loess). What was the depth of that soil, and what formation underlay it? Was there any possibility of the area becoming waterlogged through constant irrigation, or in time rendered unfit for irrigation, owing to a comparatively small depth of black cotton soil being underlain by an impermeable rock? Sections FF and GG, Figs. 4, Plate 2, showed the black cotton soil to be only about 10 feet in depth, overlying conglomerate. The Author stated that hitherto millet had been the only crop grown on the area, and that the crop was precarious, because the tropical rains on which it was dependent were extremely variable: some reference to the seasons and rainfall of the locality seemed desirable, and it would be interesting to know the seasons into which the year was divided, and the mean monthly rainfalls. The Author stated that the heaviest rains occurred in July and August, and the dry period was between October and July. Was the millet sown after the tropical rains, so that it derived the necessary moisture for its growth from the water retained in the clay soil? The Author stated that pumping experiments made by the Sudan Government showed that cotton could be grown on the area during the flood season of the Blue Nile, although in Egypt climatic conditions were such that cotton must be planted in March; and by planting on the rising flood of the Blue Nile in July, the cotton on the Gezira plain was assured of an ample supply of water, except towards the end of the cultivating season, in February and March. It would be interesting to know the season and period of the cotton-crop in the Anglo-Egyptian Sudan; the number of waterings; and the total depth of irrigation plus rainfall required to bring a cotton-crop to maturity, from seed time to harvest. Did the seasons and periods of the maize crop, and the lubia or fodder crops correspond with that of cotton? *Fig. 6* showed that the canal supplied water for irrigation from the 15th July to the 15th April, but it was stated that crops were at maturity in most years at the end of March. The irrigation period would therefore be about 240 days. Had any estimate been made of the saving that would have accrued if the dam had been built with homra or surkhi mortar? Of the rubble masonry in the dam, 54,860 cubic metres had been built with a mortar compounded of 3 parts of burnt clay to 2 of lime; a less quantity of burnt clay, and an addition of clean sand, would reduce the tendency of the mortar to shrink and increase the resistance to crushing. In India a mortar composed of 1 part of pure lime, burnt and slaked, 1 part of surkhi and 1 part of clean sharp sand gave excellent results, if well ground, screened, and mixed. In the case of the Assuan dam Sir Maurice Fitzmaurice

Digitized by Google

had stated that a mortar composed of 3 parts of burnt clay and 2 of lime with 10 per cent. admixture of sand was excellent and much more watertight than a 4-to-1 cement mortar, if carefully ground, screened, and mixed. The tensile strength of the mortar after 28 days was 160 lbs. per square inch, the lime being a pure calcium carbonate. The reasons given by Sir Maurice why it had not been used on the Assuan dam were that the plant required for its manufacture to keep pace with the contract rate of construction would have been enormous, and that all coal had to be imported from England; consequently English Portland cement had been used. The difficulties of plant and fuel did not appear to have existed at Sennar. Mr. Lacey.

Mr. W. L. STRANGE observed that the Paper was practically confined to a description of the construction of the dam of the most recent large irrigation scheme on the Nile. Despite the intense heat and the remote situation, of the works, they had been carried out expeditiously, almost entirely by native labour, and their successful completion within the contract time reflected the greatest credit on those responsible for their execution. The difficulty of laying the foundations of such an immense work at a considerable depth below the surface of a large river in constant flow was, of course, very great, but fortunately it had not been increased by any serious accident. The only delay had been due to financial, not constructional, obstacles; in fact, the presence of the central island in the river-bed had been of great utility, and full advantage had been taken of it. From the general point of view the chief matter of importance was the opposition of Egypt to the construction of the scheme, on the ground that it would deprive existing lower works of the supply to which they were entitled by long user. This opposition had been over-ruled by the British Government in connection with their orders passed after the murder of the Sirdar, Sir Lee Stack. The decision was considered harsh by those ignorant of the actual conditions. The principal of these, as pointed out by the Author, was that the Sennar reservoir impounded only flood water, which would otherwise be discharged unutilized into the sea, while the fair-weather flow would not be interfered with. There was, however, another consideration to be taken into account. From the bed of the extensive reservoir and from the large irrigated area a very considerable quantity of water would be returned by seepage to the Blue Nile, and would thus pass down to Egypt, at a time when an increased fair-weather flow would be of great utility to its irrigation works. Thus the construction of the Gezira scheme would not be detrimental, but on the contrary advantageous, to these works. Mr. Strange.

Digitized by Google

Mr. Strange The proposed large schemes at Gebel Aulia on the White Nile, and at Lake Tsana, the source of the Blue Nile, would similarly benefit Egypt. That this was not merely a theory but a fact was proved by experience in India, and the most important instance of that had occurred on the Indus. When great extensions of monsoon irrigation took place in the Punjab upstream, it was at first feared that the increased abstraction of water thus entailed would reduce the irrigating capacity of Sind downstream. The opposite had, however, actually happened, and the cold-weather supply of the lower Indus had since increased. He presumed that gaugings of the Blue Nile below the Sennar dam had been taken; if they were continued, they would show the effect of the construction of that work on the fair-weather flow.

The Author. The AUTHOR, in reply to the Correspondence, stated that the size of the granite hearting was the same as at Assuan, the maximum stone being the largest a man could carry.

The Sennar dam was primarily a diversion weir to raise the water in the river to such a level that it would run into the main canal. It also stored some water. According to Mr. H. T. Cory, of the Nile Projects Commission, only 10 per cent. of the expenditure on the structure should be charged to storage. This would reduce the cost per acre-foot to £1·1. According to Sir Murdoch MacDonald's Paper[1] on the original Assuan dam, completed in 1902, its capacity was 980,000,000 cubic metres and the total cost £E.3,050,000. This represented 796,000 acre-feet and a cost per acre-foot of £3·9 (£E.1=£1 0*s.* 6*d.*). In actual size of structure this dam and that at Sennar were very similar. The cost of the latter having been £E.5,600,000, it would be evident that it was 83 per cent. more expensive. It should be remembered, however, that Sennar was a much more inaccessible place than Assuan: a large part of the labourers had to be transported more than 1,000 miles and back again every year.

The whole of the expenditure on the Sennar dam and the canals was charged to the irrigation area. The Sudan Government had built the dam and excavated canals to bring water within 1,300 metres of any point on the fields. From these a company called the Sudan Plantations Syndicate dug the field channels and made all the other arrangements with the native cultivators, including supply of seed, advances of money, mechanical ploughing, supervision, and ginning and marketing of the cotton. After deducting the actual cost of ginning and

[1] Minutes of Proceedings Inst. C.E., vol. cxciv (1913), p. 249.

Digitized by Google

marketing, the proceeds of the sale of the cotton crop were divided in the following manner: 35 per cent. to the Government, 25 per cent. to the Sudan Plantations Syndicate, and 40 per cent. to the cultivators. Out of the 35 per cent. the Government had to meet interest and sinking-fund on the loan which had been raised to carry out the dam and Government canals. The Author.

The Paper was not intended to deal in detail with the canals.

The depth of the black cotton soil, which was a stiff loam containing 55 to 60 per cent. of clay, ranged from 5 to 20 metres. It overlay sand. There was no conglomerate or rock, such as occurred at the site of the dam. The subsoil water-level was at a great depth below the ground—up to 40 metres. Therefore, there seemed to be no fear that it could ever rise to such a level as to cause water-logging of the soil. Space had been left for the digging of open drains for the removal of surplus surface water, should they be found necessary in the future. Up to the present, the agriculturists did not consider that they were needed. The average rainfall in the south-east of the area was 400 millimetres (15¾ inches) per annum and that diminished to 150 millimetres (about 6 inches) at Khartoum.

The rain-grown millet was planted as soon as sufficient rain fell, usually in July, and was watered by that falling subsequently. Rain occurred in June, July, August, and September, the heaviest falls being in July and August. On the 300,000-acre area, the average crop of rain-grown millet was 20,000 tons. Under irrigation there would be the following rotation: first year cotton, second year fallow, third year 40 per cent. millet and 60 per cent. lubia (a leguminous crop). It was expected that the 300,000 acres would produce 30 million lbs. of cotton lint, in addition to the seed, 15,000 tons of millet, and the lubia, which was used as cattle-fodder. The millet and lubia would be taken entirely by the native cultivators. Sowing and resowing of the cotton took place from the 15th July to the 15th September. Water was given every 12 to 18 days, the interval depending on the time of year, the waterings being rather more frequent in October, with wider intervals in the colder months of December and January. It was supplied on or shortly after the 15th July at the rate of about 450 cubic metres per acre. About fourteen waterings were given in all. The millet cultivation depended mainly on the rains, but sufficient water was allowed to ensure the ripening of the crop. This was given either at the time of sowing, at the beginning of August, or later, at the end of September or beginning of October, according to the circumstances of each year and the actual rainfall

Digitized by Google

The Author. on any particular plot. Lubia received about four waterings at intervals of 20 days, beginning in September.

With regard to the mortar in the dam, the production of the clay and, in particular, of the lime for the "homra" mortar in the 54,860 cubic metres of masonry, had been a matter of great difficulty. It would have been impracticable in the time to produce the required quantities for the masonry built in 1924, which was three times as much. It also had the disadvantage that it was very slow setting—an important point in a work which was being built rapidly. When the war made it necessary to consider the replacement of imported cement by a mortar made from local materials, it was decided to use the lime and clay in the most scientific manner by erecting a cement-factory to turn them into cement, rather than to employ the same materials in the form of lime and "homra." Even if the production of the necessary quantities of the latter had been practicable, it was estimated that there would not have been any saving in cost.

Regular discharge-measurements by current-meter had been and were being taken of the Blue Nile at a short distance below the dam and a few miles above the junction with the White Nile at Khartoum.

It would be interesting to see if the low-period discharge of the river was increased by seepage from the bed of the reservoir and also from the irrigated area, as envisaged by Mr. Strange. Owing to the general impermeability of the soil, the Author would be surprised if there were any appreciable increase.

In conclusion he wished to thank the members for the kind way in which his Paper had been received and to endorse all that had been said as to the efficient way in which the Contractors had overcome the many difficulties and successfully completed the works within the contract time, which was very short for the amount of work involved. To indicate the rate at which it had been executed, he might mention that one monthly certificate amounted to £E.220,000.

Digitized by Google

23 March, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D.Eng., President, in the Chair.

The PRESIDENT, in announcing the deaths of three distinguished Members of The Institution, stated that the Council had passed the following resolution :—

> "That the Council record the regret with which they have learned of the deaths of Sir Bradford Leslie, K.C.I.E., Sir Philip Watts, K.C.B., LL.D., F.R.S., and Professor William Henry Warren, LL.D., former Members of Council, and that an expression of it be conveyed to their respective families."

The President observed that Sir Bradford Leslie had died at the advanced age of 94, having been connected with The Institution for 54 years. He had done magnificent engineering work in the course of his long life. Sir Philip Watts had given very distinguished engineering service as Chief Constructor of the Navy, in fact, he might be said to have been the parent of the modern battle cruiser; he introduced quite a new type of vessel into the British Navy, with two essentials which had not appeared so conspicuously before, namely, power of attack coupled with speed; and he (the President) thought that Sir Philip's designs of battle cruisers had been copied in all the navies in the world. Professor Warren was well known as a distinguished Professor of Engineering at the University of Sydney.

The following Paper was presented for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

(*Paper No. 4592.*)

"The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland."

By ALFRED EDWARD TUFFLEY, Assoc. M. Inst. C.E.

EIGHTY miles south of Gladstone and 80 miles west of Bundaberg lies the approximate centre of a tableland 3,000 square miles in extent. This tableland (*Fig. 1*) is bounded on the north by the Dawes range, on the east by the Burnett range, and on the west by the low divide between the Burnett and Dawson waters. The land

Digitized by Google

slopes southwards from an altitude of 1,500 feet above sea-level at the Dawes range to about 400 feet at the southern end. The whole of this area is drained by the Northern Burnett river and its tributaries. The tops of the Dawes and Burnett ranges are covered with vine scrubs containing large quantities of hoop-pine (*Araucaria*

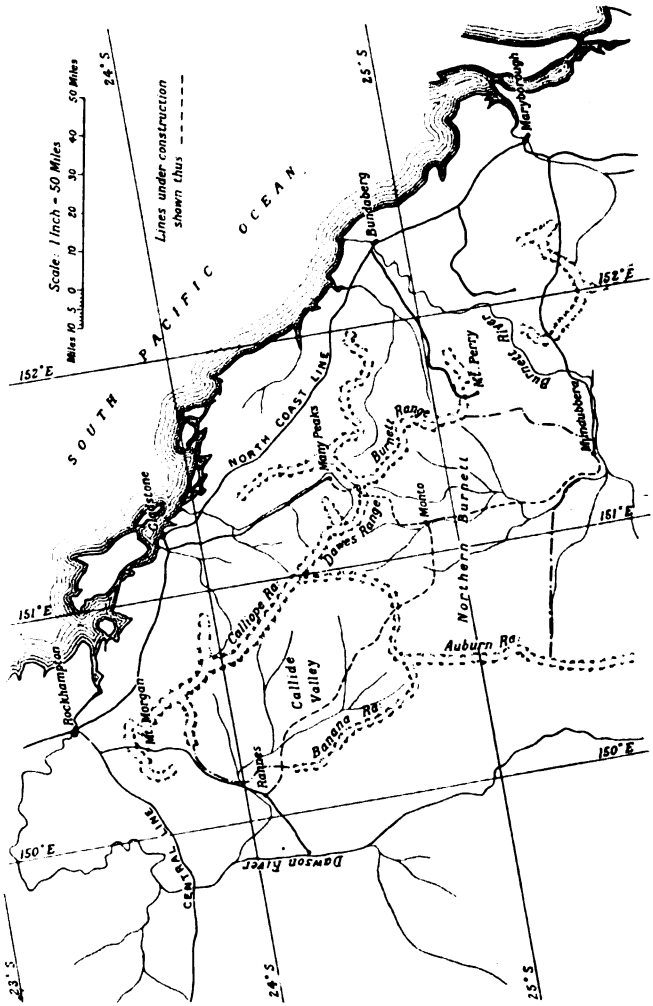


Fig. 1.

Cunninghamii), which is the most extensively used soft wood in Queensland. Smaller quantities of valuable hardwoods, of which the most important are ironbark, spotted gum, and blue gum, are spread over the remaining area of the tableland.

The northern and eastern portions of the tableland contain copper,

Digitized by Google

gold, silver, and lead mines. Great difficulties were experienced in the transport of material to the mines, and of the ore to the nearest railway-station, namely, Many Peaks. Transport over the range was carried on by means of horse- and bullock-wagons, on rough and boggy tracks with gradients up to 1 in 3; consequently only the richest portions have been worked. Haulage from Many Peaks to Mount Cannindah mine, a distance of only 16 miles, cost £4 at on. The tableland consists mainly of well-grassed ridgy country, with extremely rich agricultural flats along the creeks, and large areas of scrub land in the south. The whole area, which experiences an average rainfall of 30 to 40 inches and has a moderately dry and clear atmosphere, with bright sunshine for almost the whole year, is extremely well suited for cotton-growing, and increasingly large areas of cotton are being planted each year. Potatoes, maize, lucerne, and other crops are also grown. The land is suitable for dairy farming, which is generally carried on in conjunction with the growing of cotton and other crops.

The Northern Burnett Settlement Scheme.—Until 1922 the country was held by squatters in holdings of 5,000 to 15,000 acres, being used almost entirely for horse- and cattle-raising. Owing to the gradual increase of the population of Queensland and the necessity for fully developing the State, the Queensland Government, realizing the great agricultural and pastoral value of the Upper Burnett river district, decided to resume all the large holdings, and to subdivide them into smaller holdings, ranging in extent from 20 acres in the richer agricultural districts to 1,200 acres in the hilly districts. This was commenced in 1922, and the holdings were thrown open to intending settlers. Early in the same year railways were begun from Many Peaks, Mundubbera, and Rannes to a junction at Monto, and connecting with the ports of Gladstone, Maryborough, and Rockhampton respectively (*Fig. 1*). The line from Rannes gives access also to approximately 2,200 square miles of the Callide valley, which has been subdivided for closer settlement under the same conditions as the Northern Burnett area. The lines from Rannes and Mundubbera traverse, in the main, comparatively open country, whereas the line from Many Peaks ascends the face of the Dawes range, which rises abruptly above Many Peaks, passing through very difficult country. The reasons for the construction of this costly line are explained by the following considerations. Gladstone, besides being by far the nearest port to the tableland, has the best and largest natural harbour in Queensland. It is, however, comparatively little used, owing to the lack of direct communication with its hinterland, which, being shut off by high ranges forming the eastern edge of the coastal plateau, has

Digitized by Google

also remained undeveloped. The mineral portion of the tableland is mainly along the top of the Dawes range. Again rich pastoral country extends westwards from the Northern Burnett lands, which may in the future be given direct communication with Gladstone by further extensions of the railway.

Location.—The general location was governed by the following factors. Many Peaks, the terminus of a branch line from Gladstone, lay on the direct route to the tableland. The valley of the Upper Boyne river, which rises in the Dawes range south of Many Peaks, offered the easiest route to the foot of the range. Also the lowest portion of the range lay in the same direct route. From the lowest gaps several preliminary lines were run down the range, and the most suitable location area was determined. The trial survey was then made to the most suitable gap on a maximum gradient of 1 in 33, and a strip of country was contoured to a width of 5 chains on each side of the centre-line, or in very steep country to a height of 100 feet above and below the centre-line. From these data the primary position of the line was located on the contoured plan and laid down in the field, levels and more detailed field-notes near the centre being taken. The position of the line was again investigated, and several slight deviations were made from the previous location. Owing to the sharpness of the spurs and the steep side slopes, the location resulted in heavy earthworks.

The gauge is 3 feet 6 inches. The maximum gradient of 1 in 33 is compensated for curvature by a reduction of 0·04 foot per 100 feet for each degree of central angle subtending a 100-foot chord. The mileage of Many Peaks is 53, that of the beginning of the ascent of the range 60 miles 50 chains, and that of the top of the range 67 miles 10 chains. The reduced levels of these three points are 504 feet, 676 feet, and 1,457 feet, respectively. Thus the length of the ascent is 6½ miles and the total rise 781 feet, being an average rise per mile of 120 feet, or an average gradient of 1 in 44. The maximum gradient (compensated for curvature) is continuous, with the exception of occasional slight easements made to obtain a better location, and lengths of 17 chains of 1 in 150 at 64 miles, and of 11 chains of 1 in 132 at 65 miles 70 chains. These two easements were introduced to give relief in ascending, and to provide stopping-places in descending, for the purpose of recharging the Westinghouse air-brake pressure. The smallest radius of curve is 5 chains, and, owing to the sharpness of the spurs, this curvature was much used. Of the total of 6½ miles, 2 miles are of this radius, and a further 1¼ mile is of between 6 chains and 10 chains radius. Cubic parabola transition-curves of a constant length of 2 chains

Digitized by Google

are used at the springs and ends of all curves up to 20 chains radius. The minimum distance allowed between curves without transitions is 2 chains, and with transitions, nil. The range on the northern face was covered with open gum and ironbark forests, alternating with dense vine scrubs. To contour the parts covered with scrub it was necessary, in order to prevent excessive clearing, to take all spot levels along straight lines.

Transport.—Owing to the rough nature of the country and to the gradually increasing height of the railway above the tracks at the foot of the range, great difficulty was experienced in the transport of material, food, and water. In the last 3 miles of line, the majority of the spurs descend from the main spur on gradients up to 1 in 5 to within a short distance of the line, and then fall suddenly on gradients up to 1½ to 1 to the bottom of the range. Although gradients up to 1 in 5 were found to be practicable for drays with loads of 1 ton, it was not practicable to make roads up all the spurs to the line, for in order to obtain a suitable gradient, it would have been necessary to locate roads on sidelong ground with side slopes up to 1½ to 1, which would have involved heavy earthworks ; neither was it practicable to make a dray track on the contour of the line, owing to the steep side slopes and rugged nature of the country. It was found more economical to haul everything up one road to the top of the range, and to distribute the material down the various spurs.

The main haulage road (*Fig. 2*), which had previously been constructed by the local Shire Council for the use of teamsters hauling timber and copper ore down the range, was not built to any ruling gradient, but followed the top of the flattest spur, the gradients ranging up to 1 in 3. The worst portions were approximately 10 chains of 1 in 3, and 10 chains of 1 in 5. Teams of five horses hauled drays loaded with 1½ ton over the roads at the foot of the range, and loaded with 1 ton up the range. Materials were taken down the tops of the spurs to points as close as possible to the line, and were lowered to the required positions by timber shoots for sand and cement, and by blocks and tackle for wagons, light rails, explosives, timber, and other requisites. Only two trips could be made each day by the teams, although the distance traversed rarely exceeded 2½ miles each way. The cost of a five-horse team per day in wages and upkeep was £2 0*s.* 10*d.* Sand was obtained by screening gravel in Glassford creek, 1½ mile from the foot of the range, and cost £1 16*s.* per cubic yard, bagged, screened, and delivered at the top of the range. Cement was supplied in bags by the Queensland Cement and Lime Company at Darra, near Brisbane, for 6*s.* 9*d.* a bag, and was railed to Many Peaks. It was carted

Digitized by Google

12 miles to the foot of the range for £1 10*s.* per ton, and carted up

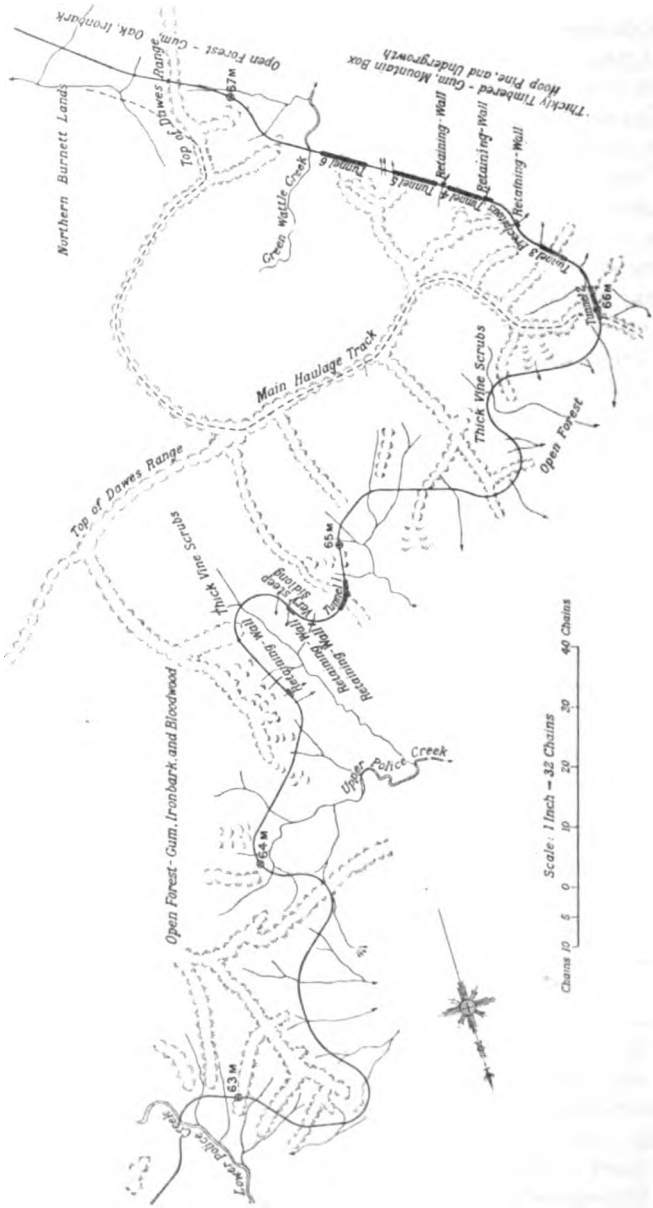


Fig. 2.

the range by the five-horse teams. The cost per bag at the top of the

Digitized by Google

range was 11*s*. The three-sided timber shoots were made of 1-inch boards, and ranged in length up to 350 feet. The longest was constructed from the top of No. 6 tunnel to the bottom of the neighbouring ravine, where a 6-foot concrete culvert, 254 feet long, was being built. In long or steep shoots the sand was bagged to prevent waste.

It was necessary to cart water from wells in Glassford creek to supply the first 3½ miles of the ascent. The remainder of the line was supplied from a well at the top of the range. The water was carted to tanks on top of the main spurs and led to the line through small pipes. Water for the concreting of tunnels Nos. 2 to 6 was conveyed from the top of the range in pipes laid on the contour of the line. The ravine at 66 miles 65 chains was spanned by a cable, from which the pipes were suspended. Carting was done by seven-horse teams, which carried 400 gallons on each journey. Each dray made two journeys per day. Such teams cost £2 10*s*. 6*d*. per diem for wages and upkeep, and water cost 6*s*. 6*d*. per 100 gallons delivered at the work.

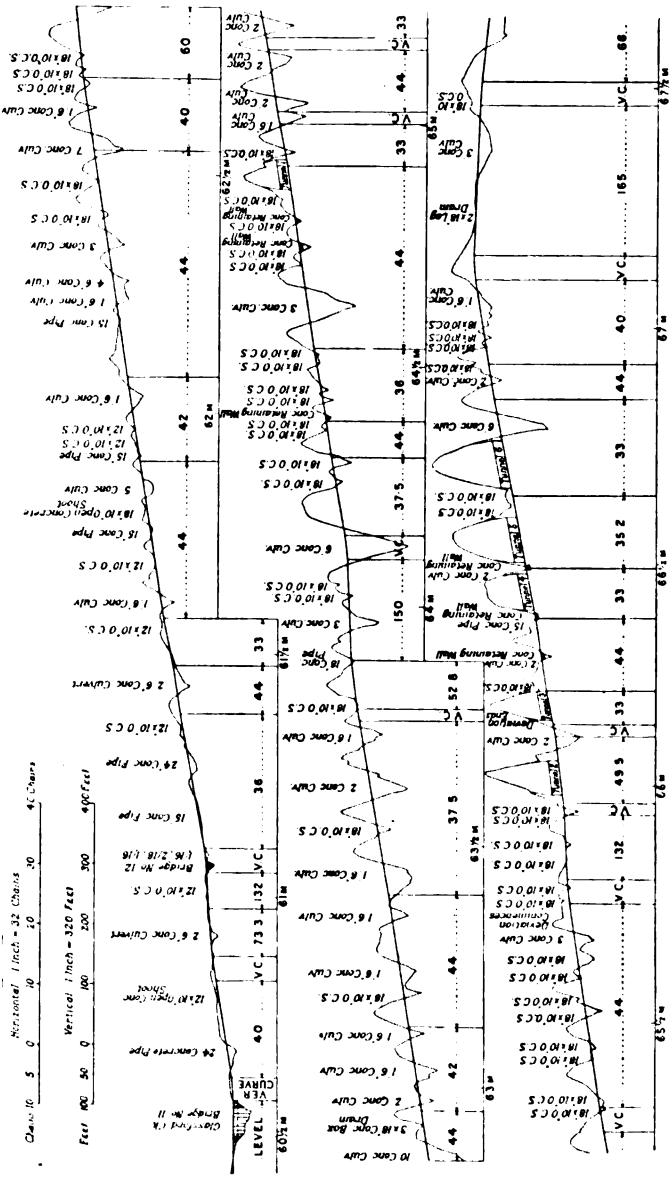
Conditions and Rates of Pay.—The Many Peaks-Monto line is being built by daywork. The only contracts let were for the quarrying and breaking of 2-inch metal for concrete for drains and retaining-walls, and for the supply of timber for bridges and tunnels. The rates of pay for the various classes of work are: earthworks, labourers 15*s*. 2*d*. per day, gangers 19*s*. 2*d*.; hammer and drill men, jumpermen, battermen and spallers 16*s*. 2*d*. per day, the average wage per man per gang being about 16*s*.; tunnel excavation, miners 19*s*. in dry ground, £1 in wet ground or where close timbering was required; concrete workers in tunnels, 17*s*. 10*d*. per day. The time worked per week was 44 hours, less two "smokos" of ¼ hour each per day, being a net time of 41¼ hours. During wet weather when no work was done, full rates were paid. All workers were supplied with tents and canvas stretchers.

Earthworks.—The cuttings, with few exceptions, were through rock, overlain by a few feet of earth. The main species of rock passed through were fine-grained igneous rock, indurated shale, clay shale, quartzite, volcanic tuff, and porphyrite. The quantities of earthwork in cuttings and banks were estimated from cross sections, assuming a batter of 1 to 1 in cuttings, and 1½ to 1 in banks, and the disposal was arranged from these quantities. A section of the centre-line is shown in *Fig. 3*. It was found, however, that the material bulked in the banks after settlement for 1 year to an extent ranging from 30 per cent. in rubble and disjointed rocks to 55 per cent. in solid rock mixed with a moderate percentage of disjointed rock. The batters of the majority of cuttings were therefore steepened to ¾ to 1, except in solid rock, where they were made as steep as was

Digitized by Google

consistent with the stability of the ground. Only one slip of any

Fig. 3.



size occurred after the completion of the cuttings. One cutting, the earth from which was tipped to spoil, passes through loose disjointed

Digitized by Google

rock, and was taken out with ¾ to 1 batters. The slip occurred after heavy rains, exposing a face of rock to which it was necessary to align the batter. It was found that rock and rubble banks stood at a batter of 1⅜ to 1. The Author considers this batter stable in rock banks, but in the case of soft disjointed rocks and rubble a batter of 1½ to 1 becomes ultimately necessary for stability.

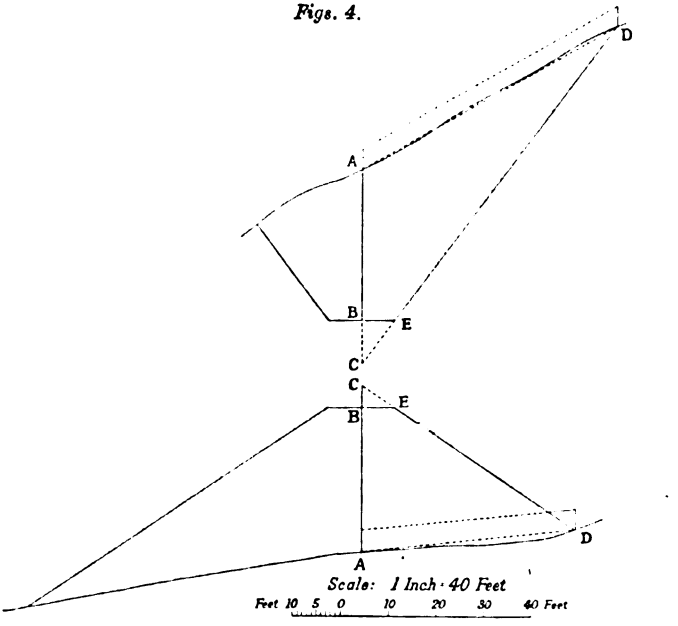
The formation width of cuttings was 13 feet, and of banks 14 feet. The cuttings range in depth up to 60 feet, and the banks up to 105 feet. The largest cutting contains 56,000 cubic yards, and the largest bank 106,000 cubic yards. Headings were driven through the largest cuttings, the earth being run through the heading into the trucks below. The gullet of the cutting was kept ahead as far as possible, leaving the batters to be pulled down as required. By this method earth was left along a considerable length of the heading, and it was possible to fill several wagons simultaneously. At the commencement of the work, the drilling for blasting was done by hand. Later, air-compressors and jack-hammers were used, with considerable saving in the cost of excavation. The air-compressors were made by the Waukasha Motor Company, Wisconsin, the two kinds mostly used being Types 14 and 20. In the former the compressor has two cylinders with 8-inch bore and 8-inch stroke, and runs at 450 r.p.m., the displacement of free air per minute being 210 cubic feet. The maximum working-pressure of air is 100 lbs. per square inch. The compressor is driven by a four-cylinder motor of 4¾-inch bore and 6¾-inch stroke. In Type 20 the compressor has two cylinders with 7-inch bore and 6-inch stroke, and runs at a maximum speed of 600 r.p.m., the displacement of free air being 160 cubic feet per minute. It is driven by a four-cylinder motor of 5-inch bore and 6-inch stroke. When placed near the work, each compressor would drive three jack-hammers. Timber wagons holding 2 to 3 cubic yards were used in the large rock cuttings under headings, and 1 cubic-yard Koppel wagons were used in the smaller cuttings.

Method of Setting Out Batter-Lines.—The batter-lines of all cuttings and banks were set out before excavation was commenced. The batter-lines of cuttings were sometimes modified by the formation of the country, but even so were necessary as a guide in the earlier part of the work. Owing to the facts that most of the material from the cuttings stood at a batter of 1⅜ to 1 when first tipped on the bank, and that a batter of 1½ to 1 was considered necessary for stability, batter-pegs were also put in to mark the required toes of the banks. Owing to the considerable depths of the cuttings and the steep transverse slopes, the batter ran out in some instances to a horizontal distance of 150 feet from the centre-line, and to a height above the

Digitized by Google

natural surface at the centre-line of 100 feet. To lay out these batters by the usual method with the level would have been a long and tedious process. To obviate this difficulty the Author devised the following method. If the vertical line AB (*Figs. 4*), representing the central depth of a cutting or bank, be produced to meet a batter line DE (of a given slope) produced at C, a triangle ACD is formed in which one side is known—namely, depth of cutting + ($\frac{1}{2}$ formation-width × tan angle BEC)—and one angle ACD. If the slope of the ground AD is known, the three angles of the triangle are known. By assuming AC to be unity, and assuming slopes for the ground AD,

Figs. 4.



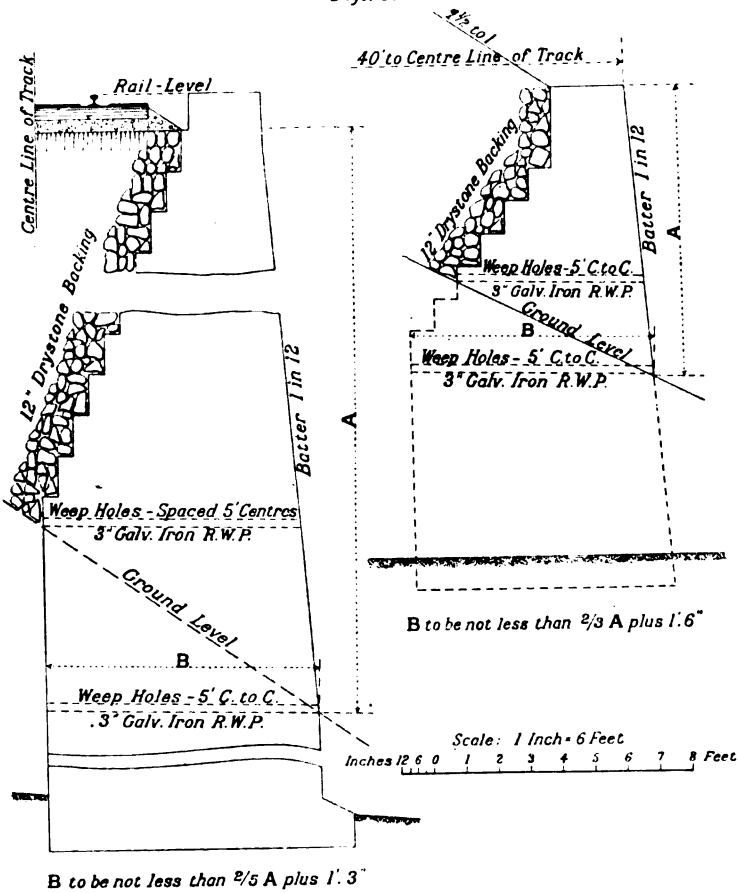
the distances AD were calculated for every $\frac{1}{4}$ degree by the formula AD = AC sin ACD/sin ADC. Tabulated results are given in the Appendix. Before proceeding to the field the actual vertical distances AC are entered in a field book.

The Field Procedure.—The engineer and chainman each hold a rod of equal length (4 feet 6 inches has been found to be suitable). The engineer, taking the approximate slope of the ground with a good clinometer, calculates the distance out of the batter-line on the slope, by multiplying the vertical distance by the number in the tables corresponding to the slope read. The chainman holds his rod vertically at this distance, and the engineer from the top of his own rod takes the exact slope, and calculates the distance

Digitized by Google

for this slope anew. If this slope agrees with the first sight taken, the peg is driven; if not, a new sight is taken at the new distance calculated. The position can generally be found after two readings. With the help of a slide-rule the distances can be calculated with ease and expedition, and with very little liability to error.

Figs. 5.

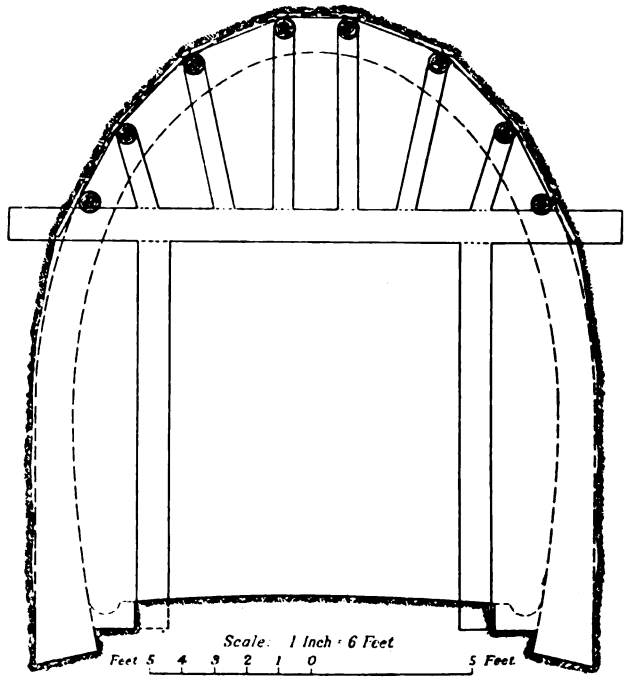

Centre Line of Track
Rail-Level
12" Drystone Backing
Batter 1 in 12
A
Weep Holes - Spaced 5' Centres
3" Galv. Iron R.W.P.
Ground Level
B
Weep Holes - 5' C. to C.
3" Galv. Iron R.W.P.
B to be not less than 2/5 A plus 1'. 3"
2½ to 1
40' to Centre Line of Track
12" Drystone Backing
Batter 1 in 12
A
Weep Holes - 5' C. to C.
3" Galv. Iron R.W.P.
Ground Level
B
Weep Holes - 5' C. to C.
3" Galv. Iron R.W.P.
B to be not less than 2/3 A plus 1'. 6"
Scale: 1 Inch = 6 Feet
Inches 12 6 0 1 2 3 4 5 6 7 8 Feet

The calculated distances being the distances on the slope, no slope corrections are needed. By the level method, where six or seven settings of the level are necessary, the liability to error is greater and the work is increased immensely. Less assistance is needed in setting out batters by the clinometer method. The Author considers that even with small side slopes the clinometer method is much quicker and simpler.

Digitized by Google

Retaining-Walls.—Six concrete retaining-walls were built on this section. Typical sections are shown in *Figs. 5*. The mixture was 6 parts of 2-inch broken stone, 3 parts of river sand, and 1 part of cement. The stone was obtained by opening up small quarries on the hillside above each retaining-wall, and was lowered in shoots as required. Before the walls were built, the sites were investigated, and the ground below the centre-line was contoured. In two cases it was found that by building the wall farther from the centre-line, a much shorter wall sufficed, resulting

Fig. 6.



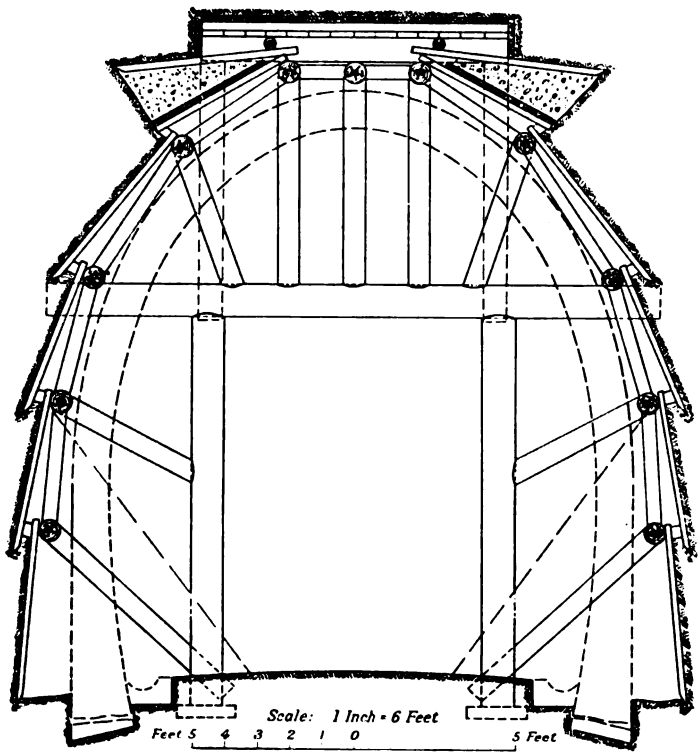
in a great saving in concrete. As in both these cases spoil filling was available, a big saving in the final cost was effected. Drainage was effected by 12 inches of stone backing and two rows of weep-holes. In several other cases where abundance of spoil was available it was decided to replace intended retaining-walls by embankments. In these cases extra width of bank was provided, the hillside was well benched, and due allowance was made for subsidence. The batters of the banks in some of these cases extend down the hill as much as 250 feet, measured along the batter. The

Digitized by Google

quantity of concrete in the largest wall was 600 cubic yards, and the average cost of concrete in situ was £5 6*s.* per cubic yard.

Tunnels.—The six tunnels, having a total length of 800 yards, ranged in length from 105 to 170 yards, and the heights of ridges above formation-level varied from 80 to 125 feet. Tunnel No. 1 was wholly on a 5-chain curve, Nos. 2 and 5 were partly on curves, and Nos. 3, 4, and 6 wholly on the straight. In all cases except No. 2 the whole of the excavation was taken out before concreting was

Fig. 7.



commenced. Tunnel No. 1 was excavated through 3 chains of volcanic tuff and 2 chains of clay shale. The rock was considerably fissured, and it was necessary for safety to stay the roof with timber as shown in *Fig. 6*, until concreting was commenced. The walls were left temporarily without support. The concrete was built up on strongly-made centering. In concreting the roof it was found advisable, in order to prevent falls of rock, to remove the longitudinal bars one by one as the concrete reached them. This left a span of only 3 feet

Digitized by Google

of roof temporarily unsupported while concreting. Recesses were built in the walls at every chain on alternate sides, for escapes. On sharp curves the tunnel was built 3 inches inside the centre-line of the road to allow for the extra clearance necessary. The formation was made level across the tunnel, the cant being given by the ballast. All drilling in this tunnel was done by hand. The neat excavation per linear yard of tunnel was 31 cubic yards. The cost of excavation was £52 per linear yard. Tunnels Nos. 3, 4, 5, and 6 pass mainly through close-grained igneous rock, enclosed between layers of andesite, indurated shale, and volcanic tuff at the extremities. The rock generally was only slightly fissured. The greater part of the excavation was allowed to stand without support until concreted (a period of 12 to 18 months), and no bad effects from weathering were experienced. It was necessary to concrete all the tunnels. Air-compressors and jack-hammers were used in the greater part of these tunnels. The cost of excavation per cubic yard ranged in different classes of rock from £1 7*s*. to £2 10*s*. for hand drilling, and from 18*s*. to £1 15*s*. when two jack-hammers were supplied to each gang of fourteen men; the power drills thus cheapened the work by one-third. Tunnel No. 2 was 126 yards in length and passed wholly through decomposed porphyrite. The greatest depth of the hill above formation-level was 125 feet. The excavation was commenced from the southern end, owing to the firmer nature of the ground there. For 60 yards but little difficulty was experienced; the porphyrite was easily picked out, and no explosives were used. A small top heading was driven 10 to 15 feet ahead and then widened out to the neat excavation, the crown being supported by timber as the excavation was widened, by the same method as used in Tunnel No. 1 (*Fig. 6*). The lower part of the excavation was taken out in one piece, the face being kept about 20 feet behind the top heading. At a distance of 60 yards from the mouth, the roof became very unstable. It was then decided to concrete the portion excavated, the timber being removed as in Tunnel No. 1, and to excavate from the northern end by a different method. This end was very much more decomposed and ran feebly on being disturbed. It was decided, therefore, to support the excavation so that all timber would be clear of the concrete lining. A top heading 8 feet by 8 feet was driven in the usual way by driving poling boards at the tops and sides with a slight upward and outward inclination to allow of the next set being placed in position. Sets were placed 5 feet apart. Owing to the fineness of the ground, close timbering was necessary. The caps were kept 11 inches clear of the finished concrete, and on the completion of the heading they were caught up by longitudinal bars of ironwork 8 inches in diameter, supported by struts resting on

Digitized by Google

temporary sills. The heading was then widened out to the size of the arch by driving poling boards transversely, the legs under the caps were removed, and the temporary sill was replaced by a horse-head, which in turn was supported by 12-inch legs resting on sills (*Fig. 7*). To place the first longitudinal bar below the crown in position, a row of poling boards was driven to support the earth. After a set of poling boards was driven off this bar, slabs were laid from it to the upper longitudinal bar, and the space above the slabs was well packed with material excavated from the tunnel. The lower part of the excavation was taken out inside the dotted lines (*Fig. 7*), the earth standing to this batter, and the batters were then removed as each successive row of boards was driven into place. In order to allow of the struts, horseheads, and legs being removed as the concreting progressed, the longitudinal bars were allowed to project 4 feet beyond each set, and were then caught up by concrete and centres. The concrete was carried up to the longitudinal bars, and the space between this and the slabs was well packed with rubble. The timber used in staying the tunnel was mostly ironbark and spotted gum, which was cut within a few miles of the work.

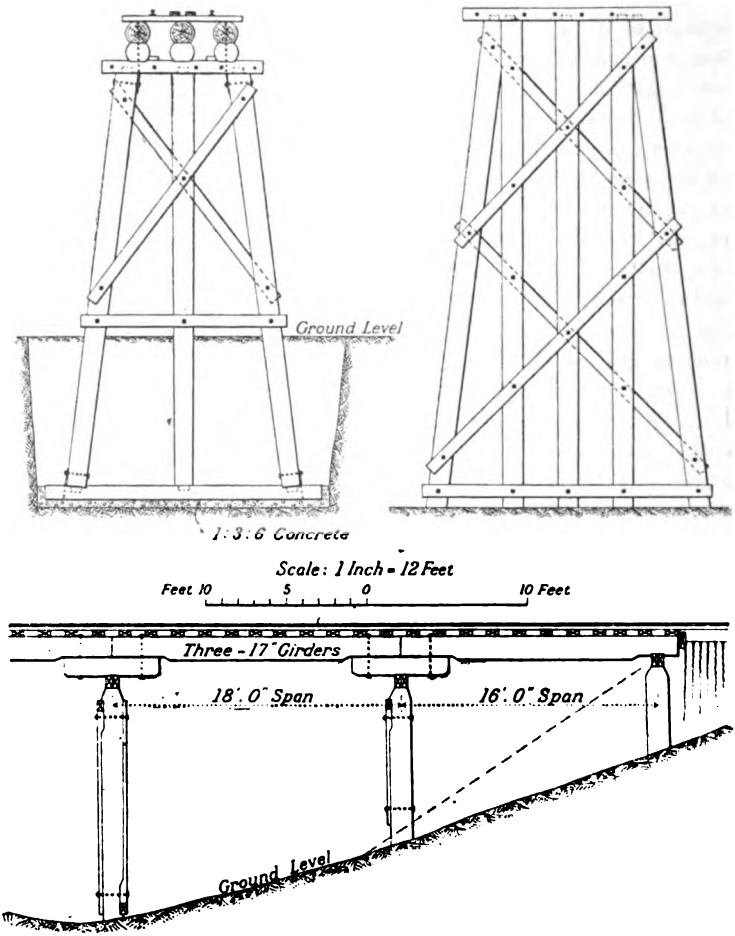
Waterways.—Under banks up to 10 feet in height, concrete pipes 18 inches to 2 feet in diameter were laid. These pipes were pre-cast in Glassford creek and laid in place on a 3-inch bed of concrete. In low banks, where less than 2 feet of filling was obtainable over the drain, concrete box drains were used. The bottoms and sides were cast in situ of 1 : 3 : 6 concrete, and the top slab was made of 1 : 2 : 4 concrete and reinforced with old rails. The cost of concrete per cubic yard was £5 14*s*. On steep slopes where only small areas had to be drained, contour drains were cut around the hillside, and the water was led across the formation through open concrete shoots, 12 inches by 10 inches and 18 inches by 10 inches in size, made up of 2-inch reinforced-concrete slabs pre-cast in the creek. In banks exceeding 10 feet in depth, concrete arch culverts were used, ranging in size from 18 inches to 10 feet in diameter. Where it was necessary to build culverts on a very steep slope, the foundations were stepped to prevent the drain from creeping and hence cracking. In some cases in deep ravines where the gully fell quickly it was possible to shorten the culvert considerably by placing it well up the side of the ravine, and diverting the stream into it. In none of the larger culverts was this possible, and these were subjected to earth-pressure from banks ranging up to 100 feet in depth.

Bridges.—Eleven timber trestle bridges were built on this section, one of which was on the ascent of the range. All spans were 18 feet, except end spans, which were 16 feet. Ironbark, cut from the forests in the district, was used generally for piles and

Digitized by Google

girders. As good foundations were obtainable at all bridges, the piers were silled. The excavation was carried down to rock or to a minimum of 10 feet, and the sill was embedded in a block of concrete. Where they are on rock less than 10 feet below the surface, the sills are secured by anchor-bolts grouted into the rock. The

Figs. 8.



tops of piles are connected by two 9-inch by 6-inch headstocks, bolted together, on which the superstructure rests. The piers are composed of three, four, or five piles, according to the height of the bridge, braced with 9-inch by 5-inch Queensland hardwood (*Figs. 8*). The superstructure consists of three 17-inch girders placed side by side on corbels 6 feet long resting on the piers. Transoms 9 inches

Digitized by Google

by 4½ inches are spiked to the girders at 20-foot centres, and the rails are spiked directly on to the transoms. Owing to the prevalence of white ants in this district, all timbers were poisoned near bolt holes by boring §-inch holes, two-thirds through the timber, and filling them with a mixture of 56 lbs. of arsenic, 20 lbs. of refined powdered caustic soda, and 30 gallons of water, the holes being afterwards sealed with wooden plugs. Backing-slabs, where required, were made of concrete reinforced on both sides, the thickness ranging from 2 to 4 inches, according to the depth below formation-level.

A steel bridge, with six 28-foot, and seven 36-foot spans, was built over Glassford creek on the level and straight, at the foot of the ascent. The 28-foot spans consist of rolled steel joists with a plate riveted to each flange. The 36-foot spans are built-up plate girders of ordinary type. The total weight of steelwork is 53½ tons. Its cost in place per ton was £62 12*s*. for the 36-foot spans and £47 12*s*. for the smaller spans. The girders rest on concrete piers 12 to 24 feet high above ground-level, and founded 10 to 22 feet deep. The concrete was carried down 2 feet into solid rock. Glassford creek, which runs on the surface only after floods, has a strong flow underground, and about 10 feet of water was met with above the rock. Steel piling, therefore, was driven through the gravel to the rock. In placing the concrete, the sheet piling was used as a form, the precaution being taken to line the piling with bags, to prevent the joints of the piling from being clogged. The piling was afterwards drawn with ease by means of a winch. In several of the excavations, owing to the occurrence of large boulders, the sides were lined with timber, and the excavation below water-level was taken out by a diver. The concrete for piers was composed of 6 parts of river stone, 3 of river sand, and 1 of cement, with the exception of the top 2 feet, which were made of 1 : 2 : 4 concrete.

Permanent Way.—The road was laid with rails, 40 feet long and weighing 60 lbs. per linear yard, made to the Australian Standard profile at Newcastle, New South Wales, by the Broken Hill Proprietary Company. Six-hole fishplates weighing 51·5 lbs. per pair are used, and the nuts of the bolts are tightened on to Grover spring washers. The joints of rails are staggered, and suspended between sleepers. The rails are secured to the sleepers by the lock spiking method, by ⅝-inch dogspikes 5 inches long. The hog-backed sleepers, 7 feet 6 inches by 9 inches by 4½ inches, are of various approved Queensland hardwoods, 2,640 being used per mile. Clean river gravel screened through a 2-inch ring is used for ballast, and was obtained from Glassford creek near the foot of the ascent by laying a siding ½ mile in length into the bed of the creek. The quantity used per mile of railway was 1,100 cubic yards, there being 4½ inches

of ballast under the sleepers. An addition to the gauge of ½ inch is made on curves of less than 8 chains radius, and ¼ inch on curves of 8 to 15 chains radius. The rails were straightened or curved before laying, by means of a hand screw-press. Super-elevation was arranged for speeds ranging from 20 miles per hour on 5-chain curves up to 40 miles per hour on 20-chain curves and over, being run out on the transition-curve, or on the first 100 feet of straight line where no transition-curves were used. Guard-rails of the same section as the running-rails were placed on all curves of 6 chains radius and less, making a total length of 2¾ miles on the ascent. The guard-rails were attached every 3 feet by means of bolts and spacing-blocks, and fastened to the sleepers by means of dogs-pikes.

Locomotives.—The heaviest locomotives which will run on this line are classified as the "B.17" and "C.19" types, and can haul 175 and 200 tons respectively over the 1-in-33 ascent. Particulars of these locomotives are given in the following Table :—

LOCOMOTIVES.

Classification	B. 17	C. 19
Type	4-6-0	4-8-0
Driving-wheels, diameter	4 ft. 0 in.	4 ft. 0 in.
Wheel-base, driving	12 ft. 6 in.	12 ft. 6 in.
,, engine	22 ,, 0 ,,	22 ,, 0 ,,
,, engine and tender	46 ,, 8 ,,	48 ,, 4 ,,
Weight, adhesive	35·45 tons	40·7 tons
,, engine	45·8 ,,	53·5 ,,
,, engine and tender	81 ,,	93·6 ,,
Cylinders, diameter	17 in.	19 in.
,, stroke	23 ,,	23 ,,
Heating-surface, tubes	1,135 sq. ft.	896 sq. ft.
,, fire-box	133 ,,	147 ,,
,, superheater	—	225 ,,
Total	1,268 sq. ft	1,268 sq. ft.
Grate-area	19 sq. ft.	21·37 sq. ft
Working pressure	175 lbs. per sq. in.	—

The design and construction of the railway were carried out under the direct supervision of Mr. R. E. Sexton, M. Inst. C.E., Chief Engineer of the Queensland Railways. Mr. T. J. Bashford, Resident Engineer, under whom the Author acted as Assistant Engineer, was in charge of the construction.

The Paper is accompanied by seven sheets of tracings, from which the Figures in the text have been prepared, and by the following Appendix.

[APPENDIX.

Digitized by Google

APPENDIX.

Batter Tables.

Banks, 1½ to 1. Batters. Down. Distance on slope = (Depth of bank + 4·66) × Sin C/Sin D.

Formation-width, 14 feet.

Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D
0	1·50	7¼	1·86	14½	2·53	21¾	4·02
¼	1·51	½	1·88	¾	2·56	22	4·10
½	1·52	¾	1·90	15	2·60	¼	4·19
¾	1·53	8	1·92	¼	2·63	½	4·28
1	1·55	¼	1·93	½	2·67	¾	4·38
¼	1·56	½	1·95	¾	2·70	23	4·48
½	1·57	¾	1·97	16	2·74	¼	4.59
¾	1·58	9	1·99	¼	2·78	½	4·70
2	1·59	¼	2·01	½	2·82	¾	4·82
¼	1·59	½	2·03	¾	2·86	24	4·95
½	1·60	¾	2·05	17	2·90	¼	5·08
¾	1·62	10	2·07	¼	2·94	½	5·22
3	1·63	¼	2·09	½	2·98	¾	5·36
¼	1.64	½	2·11	¾	3·02	25	5·51
½	1·65	¾	2·13	18	3·07	¼	5.67
¾	1·66	11	2·16	¼	3·12	½	5·84
4	1·68	¼	2·18	½	3·20	¾	6·02
¼	1·69	½	2·20	¾	3·22	26	6·22
½	1.70	¾	2·22	19	3·28	¼	6·44
¾	1·72	12	2·25	¼	3·34	½	6·67
5	1·74	¼	2·27	½	3·40	¾	6·91
¼	1·75	½	2·30	¾	3·46	27	7·15
½	1·76	¾	2·33	20	3·52	¼	7·43
¾	1·77	13	2·36	¼	3·58	½	7·75
6	1·79	¼	2·38	½	3·65	¾	8·05
¼	1·80	½	2·41	¾	3·72	28	8·40
½	1·81	¾	2·44	21	3·79		
¾	1·83	14	2·47	¼	3·86		
7	1·85	¼	2·50	½	3·94		

Digitized by Google

BATTER TABLES—*continued.*

Banks, 1½ to 1. Batters. Up. Distance on slope = (Depth of bank + 4·66) × Sin C/Sin D.

Formation-width, 14 feet.

Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D
¼	1·49	6½	1·29	13½	1·13	24	0·98
½	1·48	7	1·28	14	1·12	25	0·97
¾	1·47	½	1·26	½	1·11	26	0·96
1	1·43	8	1·25	15	1·11	27	0·95
½	1·44	½	1·23	½	1·10	28	0·95
2	1·42	9	1·22	16	1·09	29	0·94
½	1·41	½	1·21	½	1·08	30	0·93
3	1·40	10	1·20	17	1·08	31	0·92
½	1·38	½	1·19	18	1·06	32	0·91
4	1·36	11	1·18	19	1·04	33	0·90
½	1·34	½	1·17	20	1·03		
5	1·33	12	1·16	21	1·02		
½	1·32	½	1·15	22	1·01		
6	1·30	13	1·14	23	1·00		

Cuttings, 1 to 1. Batters. Down. Distance on slope = (Depth of cutting + 7) × Sin C/Sin D.

Formation-width, 14 feet.

Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D
1	0·98	11	0·85	21	0·78	31	0·73
2	0·97	12	0·84	22	0·77	32	0·73
3	0·95	13	0·83	23	0·76	33	0·72
4	0·94	14	0·82	24	0.76	34	0·72
5	0·92	15	0·81	25	0·75	35	0·72
6	0·91	16	0·80	26	0·75	36	0·72
7	0·90	17	0·79	27	0·74	37 to 45	0·71
8	0·89	18	0·78	28	0·74		
9	0·88	19	0·78	29	0·74		
10	0·87	20	0·73	30	0·73		

Digitized by Google

BATTER TABLES—*continued.*

Cuttings, 1 to 1. Batters. Up. Distance on slope = (Depth of cutting + 7) × Sin C/Sin D.

Formation-width, 14 feet.

Deg.	Sin C / Sin C	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D	Deg.	Sin C / Sin D
1	1·02	13½	1·35	21	1·74	27½	2·32
½	1·03	14	1·37	¼	1·76	½	2·35
2	1·04	½	1·39	½	1·78	¾	2·39
½	1·05	15	1·41	¾	1·80	28	2·42
3	1·06	½	1·44	22	1·81	¼	2·45
½	1·07	16	1·46	¼	1 83	½	2·49
4	1·08	¼	1·47	½	1·85	¾	2·53
½	1·09	½	1·49	¾	1·87	29	2·57
5	1·10	¾	1·50	23	1·89	¼	2·61
½	1·11	17	1·51	¼	1·91	½	2 65
6	1·12	¼	1·52	½	1·93	¾	2·69
½	1·13	½	1·54	¾	1·95	30	2·73
7	1·15	¾	1·55	24	1·97	¼	2·77
½	1·17	18	1·56	¼	1·99	½	2·81
8	1·18	¼	1·57	½	2·01	¾	2·86
½	1·19	½	1·59	¾	2·04	31	2·92
9	1·20	¾	1·60	25	2·07	¼	2·97
½	1·22	19	1·61	¼	2·09	½	3·03
10	1·23	¼	1·62	½	2·12	¾	3·09
½	1·24	½	1·64	¾	2·14	32	3·14
11	1·26	¾	1·65	26	2·17	¼	3·20
½	1·28	20	1·67	¼	2·20	½	3·27
12	1·30	¼	1·68	½	2·23	¾	3·33
½	1·31	½	1·70	¾	2·26	33	3·40
13	1·33	¾	1·72	27	2 29		

Digitized by Google

Discussion.

Sir Brodie Henderson.

Sir BRODIE H. HENDERSON, K.C.M.G., remarked that the Paper was rather difficult to criticize, because it dealt with work which presumably had been successfully carried out; but there were one or two points to which he would refer. The Author gave very useful information, in that a good many of the costs were clearly set out; and he thought that example might be followed in other Papers presented to The Institution. Such information was of great assistance to engineers, particularly nowadays when costs had changed and were still changing so much. The steep section of the railway, about 6½ miles long, was worked on the adhesion principle, but it was not stated in the Paper whether on that particular section a special type of locomotive was necessary. He imagined that it was, because *Fig. 3* (p. 128) seemed to indicate that, before the 6½ miles in question was reached, gradients were fairly easy; the gradients after the highest point was reached were not shown. If the section was worked by special locomotives, he wondered whether consideration had been given to the advisability of introducing a short section of rack line. A rack railway with a maximum gradient of 1 in 12½, or 8 per cent., and an average gradient of say 1 in 15, would have been only one-third of the length of the adhesion line and would probably have cost very much less to construct. He knew that there was a prejudice against rack lines on what might be called commercial railways, and he thought that objection was probably well founded if a combined rack and adhesion railway were used. But, where a simple stretch of rack could be introduced, worked solely by rack locomotives, there were many advantages well worth considering before adopting a steep adhesion railway. The cost of the bridgework, £62 12*s.* per ton, appeared to be extremely high, and it was difficult to understand why it should have cost so much. The rails used only weighed 60 lbs. per yard. He was under the impression that nowadays the 60-lb. rail on an important line, such as the one dealt with in the Paper, with steep gradients and considerable curvature, would not be considered, and that possibly the lightest rail advisable would weigh 75 lbs. per yard. If the axle-loads on the locomotives had to be increased at some future time, he feared that 60-lb. rails would be found to be too light. Although a good number of

Digitized by Google

sleepers were used, 2,640 per mile, they were only 4½ inches thick. The class of locomotive adopted had rather light axle-loads for a steep-gradient railway. In one type the maximum was about 12 tons and in the other it was 10 tons. It was obvious that the light rail placed severe restrictions on the design of locomotives. Sir Brodie Henderson.

Mr. VICTOR BAYLEY observed that it was difficult to criticize the location of the line, since it was impossible to make any suggestions for alternatives. Engineers who were responsible for the location of a railway were themselves the best critics, and often wished they had decided to build the line somewhere else when they came to face some of the constructional details. He thought the Author had been correct in working out the location downwards from the summit. No doubt the gradient of 1 in 33 was unavoidable, since no summit tunnel was adopted. The compensation on curves was the same as that adopted on the Khyber Railway, but from his experience of construction trains there he did not think it was quite enough. On the other hand, if too much compensation were given, it had the result of reducing the ruling gradient to an undue extent. Possibly that compensation, which had been accepted elsewhere, could be taken as a reasonable one on such railways. There were, apparently, no crossing-stations in the 6½-mile length. It seemed that the capacity of the line would be considerably reduced, and he thought that, if the traffic on the railway increased, it would be necessary to have one or more crossing-stations on such a steep section. He noted that no catch-sidings were provided. On the Khyber Railway catch-sidings had been put in by order of the Government. He did not think they had been of use, and if they had come into use they would be perhaps dangerous. The curvature, 5 chains (330 feet) radius, seemed to be very severe. The Author stated that it was necessary owing to the steepness of the ridges. Even on the Khyber Railway the sharpest curves were of 818 feet radius; and he could not help thinking that in adopting a 5-chain curve for the Queensland line the designers had given those who were going to maintain the railway a severe task. The engines would have to be heavy to pull a useful load, probably the grinding action of the flanges on the rails would be severe, and the maintenance cost of new rails would be very high indeed. However, if it was anticipated that the heavy traffic would be on the down gradient, and that only empty trains would have to be hauled up the hills, the matter might be looked at in a different light. The transport of materials of construction to the summit had been done by horses, and he thought the Author would have been well advised if he had constructed a service road. It was stated that it would have been Mr. Bayley.

Digitized by Google

Mr. Bayley. difficult and expensive, but Mr. Bayley doubted if it would have been so expensive as horse transport on the existing track. No doubt the relative merits of motor transport against animal transport had been carefully considered; the use of motor transport on a service road, however, would probably have reduced the cost particularly in connection with loss of materials due to break of bulk. No doubt there had been excellent reasons for carrying out the construction by day labour, but it must have added considerably to the cost. He noted with interest that the maximum economic depth of cuttings was 60 feet. In his experience on the Khyber Railway that had been found to be a suitable limit; when cuttings reached 60 feet in depth it was time to think of tunnels, and in some instances the alteration had been made while the work was in progress. He thought the Author was right in deciding that Nature was the best judge of a suitable side slope for cuttings in an undeveloped country. The slope of about 1 to 1½ for banks coincided with his own experience. In deep cuttings the Author drove a heading, which Mr. Bayley assumed was an open gully. It seemed to him that, while driving the heading, work on the face of the cutting was liable to interruption. A clear track must be left for the tubs to be run out from the heading, and that was not possible if blasting was going on at the face of the cutting. That must mean a loss of time, and of all the things which added to cost, delay was the most serious. He would be glad if the Author could give the total cost of the earthwork; he expected it was very high, because of the day work. The method of setting out the side slopes was interesting, and was effective when working by day labour. When work was let out by contract, however, there must be a record of the state of the ground before it was first cut, both for bank and cutting, and, if the cross sections were to be accurate, probably the method given by the Author was unnecessary. It was interesting to compare the tunnels with the 3 miles built on the Khyber Railway. According to *Fig. 7* (p. 133), the longitudinal timbers, the crown bars, and the side bars were only about 9 inches in diameter. That was a very light crown bar indeed, and, since the tunnelling had been quite successful, it denoted that the pressure of earth could not have been high, but that the timber was necessary in order to keep out loose earth and fallen rock. That being so, it seemed that the elaborate timbering had been unnecessary and had probably added to the cost of the tunnel. Timber was plentiful and probably that was the reason why that method had been adopted. In the Khyber, where timber was scarce, it had been necessary to economize in its use, and the arch part of the tunnel had been invariably put in first. A heading had been made, excavation had been carried out for a

Digitized by Google

short distance, and then the arch had been built in that portion. The walls had been afterwards underpinned whilst building down to formation-level. He was convinced that that was the best and cheapest method of tunnelling. Once there was masonry overhead, the rest was child's play. He felt inclined to criticize adversely the section of tunnel employed. The side walls appeared to be very flat, and the slight arch owing to the curvature of the inside appeared not calculated to resist the side pressure which always came sooner or later in any tunnel. The cost of excavation, £52 per linear yard, struck him as a very high figure; possibly it was due to the trouble taken by the Author to excavate and timber the whole cross section before putting in any masonry. Delay there tended to increase costs. The cross section of the tunnel—31 square yards as deduced from *Figs. 6* and *7* (pp. 132 and 133)—was about one-half of the cross section of the tunnels on the Khyber Railway, but the cost of the excavation per linear yard in the Khyber had been less than the cost given in the Paper. He noticed that the rail was rolled to the Australian standard profile. He was not aware that there was an Australian standard which was different from the British standard, and he thought it was a pity. Mr. Bayley.

Mr. H. W. S. HUSBANDS asked whether future conversion to the standard gauge had been taken into consideration when the designs were prepared, or whether the railway had been built to some loading-gauge adopted only by the Queensland Railways? From *Figs. 6* and *7* it appeared that it might have been built to the 1905 standard gauge, for although of the same width as the later gauge of 1912, the height was only 17 feet from the formation, as against 17 feet from rail-level. That section had been adopted in 1912 with a view to the unification of the loading-gauge in Australia, but he was afraid it had only been used on the Commonwealth lines. If new lines continued to be built to the old loading-gauge, he was afraid the date of final unification would be further postponed. If it was proposed to convert the present line rather than to build a new line when the time came for conversion, the curves were certainly very sharp for a 4-foot 8½-inch gauge line: and he thought there was no intention to convert. Also it would appear that the retaining-walls had been put as close as possible to the formation, and there did not seem to be sufficient room to increase the formation-width. There was no mention whether the actual tunnel-profile was enlarged on sharp curves, which, of course, would presumably be done, but he noticed that, although the curvature was about 17 degrees, the movement of the centre line was only 3 inches, whereas, according to the Indian standard Mr. Husbands.

Digitized by Google

Mr. Husbands. given in Mr. Bayley's Paper,[1] the allowances made for a curve of only 7 degrees were an extra 8 inches outside and 20 inches inside, necessitating an 8-inch shift. Was the six-bolt fish-plate the Queensland or Australian standard? He remembered some trouble with six-bolt fish-plates on the Nizam's Railway, and Mr. C. W. Lloyd-Jones, Assoc. M. Inst. C.E., who investigated the matter, found[2] there was no real advantage in using fish-plates longer than 14 inches, with two bolts, and four bolts were found sufficient in the best English practice.

Mr. Willox. Mr. W. A. WILLOX remarked that, at first sight, one might be inclined to question the necessity of a 1-in-33 gradient, in view of the possibility in such railways of cutting a summit tunnel to avoid going right over the top of the range; but in the present instance, apparently, from the information given at the beginning of the Paper, a table-land had to be reached, and presumably the gradient rose simply to a gap in the mountain peaks leading straight on to the table-land. He thought that that probably was the case, because no gradient on the reverse side was shown in *Fig. 3* (p. 128). The extraordinary method of conveying the materials to the top of the range required a little more justification than was given. There were many methods alternative to the somewhat cumbrous animal haulage that had been used. For instance, a ropeway was generally quite cheaply and easily constructed, and it would be interesting to know whether that had been considered, and, if so, what objections had prohibited its use. The locomotives described did not appear to be suitable for working economically such a heavy gradient. No doubt the Author was not responsible for the design of those locomotives, which probably were standard types in use on the Queensland Government Railways. The "Garratt" and other articulated types presented very considerable advantages when light axle-loads were required in conjunction with great power, and would appear to be suitable. The question whether it would have been possible to use a rack instead of an adhesion gradient would perhaps not arise if such special types of locomotives, which for a number of years had been found quite successful elsewhere, had been employed.

Mr. Cohen. Mr. A. J. COHEN observed that about 10 years ago he was assistant engineer on the Northern Shan States railway in Burma, where the gradient for the greater part of the line was 1 in 33, with a Ghat section of 1 in 25. The sharpest curve was 18 degrees, uncom-

[1] Ante, p. 12.

[2] "Design of Fishplate Rail-joints," Minutes of Proceedings Inst. C.E., vol. clxxxii (1910), p. 282.

Digitized by Google

pensated, and 50-lb. rails were used, even on the Ghat section. The engines were of the Fairlie type; but, when the traffic increased considerably, the Mallet articulated type, with 10-ton axle-loads, was introduced. He thought experience in India certainly proved that there was no necessity to have a rack railway on a 1-in-33 gradient. Even on the 1-in-25 gradient it was extraordinary what heavy loads could be dealt with. He anticipated that the troubles which would arise with the Burnett Railway would be similar to those he had experienced in Burma, namely, rail-wear on curves and creep. They were very severe, although the traffic was not heavy; and as the traffic grew, so the difficulties increased. The wear on the curves was the chief trouble, but even that could be greatly reduced by careful attention. It was found that greasing was of great benefit, especially when the right grease could be obtained. Creep was most troublesome on the Ghat section, where there were great differences in temperature. At first an attempt was made to anchor the important points, such as the tangents of curves on the up-hill side and the switches at stations, and a careful count was kept of the number of closed joints. By experience it was known that when a certain number of joints had closed, there would be a fracture; thus steps could be taken in time to prevent an accident. Later, creep-preventers were introduced, with considerable success where they were used in sufficient numbers. Mr. Cohen.

Sir CYRIL KIRKPATRICK remarked that he had had considerable experience of putting in the batter-lines of banks and cuttings, and he was not sure that the Author's method was simpler or quicker than the old-fashioned method. One reason why the old-fashioned method was, in his opinion, the best, was that the first job in locating was to stake out the centre-line, and then the next thing that usually happened when the workmen arrived was that the centre-line pegs were knocked out. His experience was that it was far more satisfactory to set out the batter-pegs a chain or two apart by means of theodolite and level, and the centre-pegs could then be reinstated at any time from the known positions of the batter pegs. Sir Cyril Kirkpatrick.

The PRESIDENT expressed the hope that the building of the line to the 3-foot 6-inch gauge did not mean that there was going to be real delay in standardization of gauge in Australia. He had recently had Australian visitors staying with him, and the account they gave of the difficulties which now existed, owing to the five different gauges in Australia, made him think they were undoubtedly intense. That might be a small matter from the point of view of inconvenience to the public, but the tranfer of goods between different gauges was very costly. The President.

Digitized by Google

Correspondence.

Colonel Hearn.

Colonel GORDON R. HEARN, R.E., observed that it was evident from the details in the Paper, and from the section in *Fig. 3*, that extremely heavy work was entailed, in spite of the limiting curve of 330 feet radius. This radius was less than 100 times the gauge, which on mountain railways was practically accepted for the metre gauge in India and Burma. The compensation allowed for curvature on such a sharp curve reduced the actual gradient to 1 in 44, and indeed this was stated to be the average gradient also. The total length of curve was not given, but was certainly more than 50 per cent. of the total length, since curves of, and sharper than, 10 chains radius aggregated 50 per cent. in length. Without attempting to criticize the location in detail, he would point out that even the sharp curve adopted had not avoided nearly $\frac{1}{2}$ mile of tunnelling in the aggregate, and he thought it possible that a freer use of the fall obtainable by a "stiff" alignment might have been beneficial. The necessary use of guard-rails on $2\frac{3}{4}$ miles of curves added to the expense. He was particularly interested in the sections (*Figs. 5*) of retaining-wall adopted, differing as they did so markedly from those he had adopted on the Khyber Railway. The non-surcharged wall used by the Author (if any railway retaining-wall could be so described) had a base-thickness of two-fifths of the height plus 1 foot 3 inches. On the Khyber railway it was seven-twelfths. The soil-surcharged wall on the Khyber Railway had a base-thickness of one-half, against two-thirds of the height plus 1 foot 6 inches shown in *Figs. 5*. Both could not be right, and he was sure that the design of retaining-walls was still a very controversial matter. On the Khyber Railway a better disposition of material was obtained by a front batter of 1 in 4, but apparently the "non-surcharged" wall was extravagant. There also it had been found that building walls farther away was occasionally economical. In both cases the importance of dry stone backing was recognized, and in both cases the slope of repose of the material to be retained was about 1 to $1\frac{3}{8}$. It was interesting to note that the neat excavation per linear foot of tunnel was 279 cubic feet; but the finished area was not given, and the loading-gauge might have been shown on the cross section. On such sharp curves the side swing of bogie-coaches must be very considerable. It was not quite clear why the transition-curves were not employed to run out curves on to a presumably

Digitized by Google

moderate length of straight tangent. It would be of advantage if the Author would give the superelevations adopted and the rates of running out, and state whether the 2 chains included the portion taken from the curve. Colonel Hearn.

It was very important to mark on the ground the approximate toes of all banks, so that benching could be properly done, but the guessing of the slopes of repose of cuttings was a difficult matter, and so, unless property-rights were affected, the calculations of batter-lines in cuttings did not seem essential. He had discovered a means of plotting toes of banks on the contoured plan by scaling off one-and-a-half times the fall plus half the width of formation until the levels coincided. This was useful to ascertain whether a bank would stand on the slope. But he had very seldom found it necessary to survey and contour a width of 330 feet on either side, especially on the uphill side. It was not quite clear why the poisoning of timber to prevent the ravages of white ants had been confined to a few holes bored near bolt-holes. It would also be interesting to know if the $4\frac{3}{4}$ inches of ballast under the sleepers protected them against attacks by white ants, or whether the sleepers also were poisoned. Many useful details were given in the Paper, which gave scope to thought; and the Author was to be congratulated on his industry in preparing it.

Mr. W. O. Leitch hoped the Author would supplement the Paper by giving further particulars of the costs, and would compare them, if possible, with costs by contract. Why had the work been built by day work? Cuttings up to 60 feet and banks up to 105 feet made by day labour were unusual. As it was difficult to scamp the work of making a cut or a bank, such work was usually considered very suitable for carrying out by contract more cheaply than by day labour. If quarry-work could be done by sub-contract, why not rock cuttings? The price of retaining-wall concrete, of 1 : 3 : 6 mixture, namely £5 6*s*. per cubic yard, seemed high. The batter tables were useful and represented a neat method of setting out slopes. Mr. Leitch.

Mr. G. E. Lillie remarked that the location of a railway in precipitous places had little resemblance to the same work in open country. In the former it was a matter of contours and salient points, summits and valleys, and the development of length to get the necessary rise or fall; while in open country it was a question of cuttings and banks, and the best crossings of rivers. The line described by the Author, although in very steep country, was still a line of cuttings and banks, with some minor bridges and half-a-dozen tunnels. It might perhaps be regarded as an extreme case Mr. Lillie.

Digitized by Google

Mr. Lillie. of steep, but fairly open, country. The cuttings and banks seemed to aggregate a very considerable volume and constituted a big work. The Author's method of setting out the side widths was simple and ingenious, but it implied that the cross sections had not been taken before the gradient-lines were drawn on the longitudinal section. If they had been so taken, and the batter-lines drawn thereon, it would only have been necessary to scale off the side widths and set off the amounts by tape measurements along the ground. The Author's objections to horizontal measurements in connection with cross sections were widely held, but there was no need either to adopt horizontal measurements or to use a dumpy level for this purpose. Mr. Lillie's method was to use a transit theodolite for taking cross sections, to set it up on the centre-line with the transit plane at right angles thereto, to set the telescope to a vertical angle approximately the same as the slope of the ground and fix it in that position, and then with level-staff and tape (or chain) to record the trace of the ground-surface just as if he were using a level. It was only necessary to make a note of the vertical angle used and, in plotting the cross section in the office, to draw off a line to that angle with a protractor and plot the ground-line from it. With that method, as a theodolite could easily range to the 200 or 300 feet required each side of the centre-line, one setting-up was all that was necessary for each cross section, instead of the many required when a level was used. If by any chance, owing to a declivity or a rise in the ground at any point, the level-staff was too low or too high to be read, the vertical angle of the theodolite was altered and the new angle was recorded in the field-book with the staff reading. Cross sections should always be taken before drawing the formation-line on the longitudinal section, as with their aid the centre-line could frequently be adjusted so as to save something in the quantity of excavation or bank. He had devised, and had had made, an instrument which measured the volume of a cutting or bank from the longitudinal section, the pointer of the instrument being passed round that cutting or bank as shown on the longitudinal section, just in the same way as the pointer of a planimeter was passed round an area. The edge of the base-plate had to be placed on the line representing the intersection of the side slopes (point C of *Figs. 4*, p. 130), and the backward motion of the pointer along the formation-line to complete the circuit of the figure automatically deduced the volume of that portion below formation in cuttings and above it in banks to the said intersection (or zero) line. The reading on the roller had to be multiplied by the side slope, and if the longitudinal section was not drawn to the scale for which the instrument was built, a correcting factor

Digitized by Google

(horizontal scale multiplied by the square of the vertical scale and divided by the squares of the scales to which the instrument was built) was applied. That such an instrument was a possibility was clear when it was remembered that the volume of a cutting or bank was $S\int_0^l y^2 dl$, in which S was the side slope, or batter; y the depth of cutting or height of bank, measured from point C of *Figs. 4*; and l the length of the cutting or bank along the centre-line. With the plan, the longitudinal section, and the cross sections before one, it was surprising how quickly, with the aid of that instrument, any question of adjusting the centre-line to effect a saving of excavation could be disposed of, and an estimate of the amount of cutting and bank obtained. Mr. Lillie.

With regard to the construction, he noticed that there was no masonry at all on the railway, the materials used being concrete and timber only, except in the Glassford Creek bridge, where there were steel girders. The dimensions adopted for the concrete works were generous, judging from the retaining-walls. Since the cuttings were largely through rock, which had to be removed by explosives, it seemed strange that stone masonry should not have been the cheapest material for the construction of retaining-walls, tunnel-linings, etc., as the stone was on the spot and transport charges were admittedly high. The concrete shoots carrying water across the railway (overhead presumably) from catch-water drains on the uphill side were a good idea and would have been worth an explanatory sketch. They complied with the fundamental principle of carrying rain-water off without giving it a chance of soaking into the formation. Mr. Lillie preferred catch-water walls running diagonally across the contours instead of catch-water drains, as there was a danger (especially if they should get blocked) of the latter becoming a means of letting surface water get in under the surface and become underground water, which was much more dangerous and difficult to deal with. The high-level culverts, on the other hand, violated the above principle. If they were inevitable for any reason, a line of concrete pipes with open joints should be put under the bank at the deepest point to drain off the saturation water in the bank itself.

The task of laying heavy rails to the sharp curves of a mountain railway was very difficult. On the Kalka–Simla Railway (a line of 2-foot 6-inch gauge, with the same ruling gradient as the line described in the Paper, but with curves of only 119 feet radius) practically the whole of the 60 miles of line had been relaid under traffic with 60-lb. rail; but he had found it unnecessary to adopt the

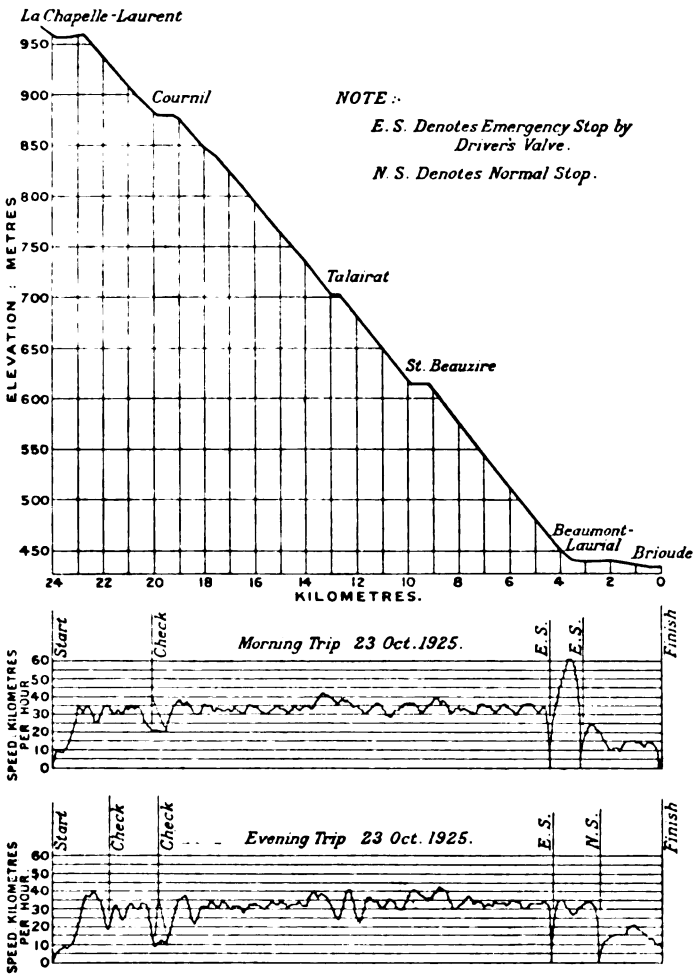
Digitized by Google

Mr. Lillie. Author's plan of bending the rails with a "Jim Crow" before putting them into the road. His method had been to place the rail in front of the last rail laid, bolt on the fish-plates, and then spring the rail into position with iron bars used as levers. Five or six men held it in position while it was secured to the sleepers with screw spikes and bearing plates, when the next rail was fished up and the process repeated. Finally, any kinks were sweetened out with the "Jim Crow." It would be appreciated that, whether a "Jim Crow" was used beforehand or not, the rail as thus bent to fit the curve of the line was not even then bent to its final shape, for it had no cant. To give it cant when bending it would involve bending it in a plane not at right angles to its height, and a rather fine adjustment would be necessary; but even then the result would probably be to curve the rail in the vertical plane also, the most fatal mistake of all. The fact of the matter was that the cant, in the case of a rail already bent to a horizontal curve, involved a certain amount of torsion in the rail, which in its final position did not conform to a cylindrical curve but to a large-angle cone, the angle of the cone being the angle of cant. It was quite impossible to bend a rail with hand gear to such complicated curves before putting it in the road. The result was, of course, that the inside edge of the rail-foot did not rest on the bearing-plate, and the inner screw spikes were merely tightened to a reasonable amount, it being left to the weight of the train to force the rail down. After a few days the rail took its correct shape and the inner screw spikes could be tightened. One small inconvenience was that the pressing of the rail down on to the bearing-plate brought the head of the rail in a little, and tightened the gauge. That had to be allowed for in laying the rails. Although it was difficult to bend those heavy rails to so sharp a curve as 119 feet radius, it was in his experience more satisfactory and in some ways simpler than bending them to rather easier curves of 300 to 400 feet radius. The reason was that bending the rails to the smaller radius sprung them beyond their elastic limit, so that once they were bent they were not perpetually trying to spring back to the straight; they took the shape of the curve at once, and retained it even if they were removed from the line. The curves of 300 or 400 feet radius and upwards did not spring the rails beyond the elastic limit, and therefore gave more trouble in maintenance for the first few months or so, as they were trying to spring back straight all the time; but after that they too settled down. In such circumstances perhaps the Author had been right to use the "Jim Crow" before putting the rails into the road. The whole subject of permanent

Digitized by Google

way on mountain railways was full of interest: it differed essen- Mr. Lillie
tially in many ways from permanent-way work and practice on

Figs. 9.



ordinary railways. One aspect had been dealt with by Mr. Lillie,[1] but many interesting problems did not yet appear to have been discussed.

[1] Minutes of Proceedings Inst. C.E., vol. ccxi (1920), p. 360.

Digitized by Google

Mr. Rendell. Mr. A. W. RENDELL observed that he had recently received data giving the profile of the line and other particulars concerning certain train trials in France, made in October, 1925, which might be of general interest as bearing on the statement (p. 124) as to the provision of easements for trains both in ascending and in descending certain gradients. The section of the Paris–Lyons–Mediterranean Railway between Brioude and La Chapelle Laurent, which was selected for these recent train trials (*Figs. 9*), had a marked resemblance to that described in the Paper. The total length, however, of the Brioude line gradient was 11½ miles, with an average rise per mile of 149 feet, or an average gradient of 1 in 35·4. The trial trains consisted generally of seventy-five wagons, weighing, with the locomotive, about 1,700 tons. There was no occasion at any time to stop to recharge reservoirs, as with the apparatus used the reservoirs were fully charged during partial releases of the brakes.

The Author. The AUTHOR, in reply to the Discussion and Correspondence, remarked that the original survey followed the contours of the ridges more closely than did the final location, being stiffened considerably by deviations, so that full advantage of the maximum gradient was taken. No further deviations, however, had been considered advisable. A summit tunnel was not practicable, as the table-land sloped from the summit in easy gradients. The contours on each side of the trial survey had been taken for the purpose of locating the final working survey. The transition-curves were 2 chains long. This included 1 chain taken from the curve. The cant was run out in the transition-curve. On curves of flatter radius than 20 chains, where no transition-curve was used, the cant was run out at a rate not exceeding 1 inch in 30 feet. That length of transition-curve had proved satisfactory on the 3-foot 6-inch gauge railway. The superelevations, which were suitable for a speed of 20 miles per hour, were 3½ inches for curves of 5 chains radius, 2⅞ inches for 6-chain, 2½ inches for 7- and 8-chain, and 1¾ inch for 9- and 10-chain curves. The loading diagram used was the standard for 3-foot 6-inch gauge railways throughout Australia. The future conversion of the line to standard gauge had not been considered, as no finality had yet been reached with regard to the unification of gauges.

The headings used in taking out cuttings had been rectangular drives or tunnels, timbered with sets placed about 5 feet apart, having slabs placed longitudinally over them. A space, usually termed "a Chinaman," about 18 inches wide, was left along the centre, and covered with short transverse slabs. The earth was shot

Digitized by Google

down on to the heading, and, by removing two or three transverse slabs, allowed to run into the trucks in the heading. There was thus no delay after firing. The Author.

The rock passed through in the cuttings was not suitable for stone masonry in retaining-walls. The price of concrete was high, owing to the difficulties of haulage. In any case masonry would have cost more than concrete.

The earth-pressure in tunnel No. 2 was high. Crown bars of ironbark timber were used, which had a very high modulus of rupture. Further, the method used in strutting between crown bars gave an arch effect, which increased the strength of timbering. In the class of ground encountered, close timbering was necessary to prevent flows of fine earth, which, by loosening the ground above the timber, would cause the collapse of the roof. In comparing the cost of this tunnel with that of the Khyber tunnels, it was necessary to consider that the miner in Queensland was paid 20*s*., and at the Khyber 1*s*. 2*d*. (he understood) per diem.

It had been the policy of the Queensland Government for many years to carry out all railway work by day-labour as far as possible. The amount of quarrying done by contract was comparatively very small. It would not be possible to obtain a reliable comparison between the costs by day-labour and contract, as no extensive railway work had been done by contract for many years, and wages and conditions of labour had changed considerably during that time.

The open concrete shoots used for waterways were placed across the formation under the rails, not overhead. The piles of bridges were poisoned near ground-level. The object of poisoning near bolt-holes was to prevent ants from reaching the interior of the pile without their presence being noticed. When ants attacked timber from the outside their presence was always indicated by the earth tunnels which they built. When such were noticed, fresh poisoning was done. Sleepers were not poisoned. While clean ballast formed a partial protection against ants, the Author believed that the continual vibration due to trains discouraged serious attacks by them.

The cost of the steelwork in bridges was high, owing to the steel having been bought during the post-war period, when prices were high, though the material was not used for some time subsequently.

Queensland timber was very strong and durable, and 4½ inches had been found to be thick enough for sleepers. Their average life exceeded 21 years, and there were instances where ironbark sleepers had lasted more than 40 years. The rails were not canted towards each other, but were laid in the same plane, as all rolling stock was fitted with cylindrical wheels. Rails weighing 60 lbs. per yard

Digitized by Google

The Author. were considered to be heavy enough for 12-ton axle-loads, which was the maximum that could be used for some considerable time on the Queensland Railways. When the lines were finally strengthened for heavier axle-loads, heavier rails would be laid as required. The guard-rails on curves were kept greased, and were so spaced that they took part of the side thrust of the wheels on the back of the wheel-flanges. With such provision, the grinding action on rails on 5-chain curves was not severe. Guard-rails had been found to increase five- and six-fold the life of the outer rail on curves. Further, when the guard-rail was greased, friction was reduced and the full efficiency of the engine was retained. Six-hole fish-plates were used in accordance with Australian standards.

From previous experience of rack railways in Queensland, one of that type had not been considered advisable.

He regretted his omission to acknowledge in the Paper a suggestion made by Mr. D. Macarthur, of the Queensland Railways, which had assisted him in devising the field procedure for laying out batters.

Digitized by Google

13 April, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D. Eng., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

ROBERT GEORGE CLARK.

SUKHENDRA NATH GHOSE, B.Sc. (*Glas.*).

And had admitted as

Students.

WILLIAM FILLINGHAM BROWN, B.Sc. (Eng.) (*Lond.*).
HENRY GEORGE COUSINS.
HERBERT VENANT CUERDON, B.A. (*Cantab.*).
BABULAL SAVJI DHOLAKIA, B.E. (*Bombay*).
GEORGE EGAN, B.E. (*National*).
NEIL GEORGE FERGUSON.
DERRICK CHILD GILDER.
GEORGE BRANSON HETHERINGTON, B.E. (*Sydney*).
JOHN HOLMES JELLETT.
JAMES MACKENZIE.
JOHN MALONE.
CECIL HERON PRIDHAM.
KENNETH MAURICE STEVEN, B.Sc. (*Glas.*).
DOUGLAS GOVAN SUTHERLAND.
LAURENCE BELL WALTON, B.Sc. (*Durham*).
NORMAN DAVID WATSON, M.Sc. (*Queen's*).
JACK BARBER WIKELEY, M.Eng. (*Sheffield*).
FRANCIS LESLEY DIGBY WOOLTORTON, B.Sc. (Eng.) (*Lond.*).
STEPHEN HERBERT HOWARD WRIGHT, B.Sc. (*B'ham*).
JOHN HASWELL YOUNG.

The Scrutineers reported that the following candidates had been duly elected as

Members.

CHARLES ANSDELL LEECH.
MATTHEW ALEXANDER ROBINSON.
PHILIP RIDSDALE WARREN.

Associate Members.

THOMAS ALFRED ANDERSON.
FREDERIC WILLIAM BUTLER, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
GEORGE HERBERT WORKMAN CLIFFORD, B.Sc. (*B'ham*), M.Sc. (*Manchester*).
MAURICE LAKE COBB, *M.C.*
JOHN HARROWER ELLACOTT, Stud. Inst. C.E.
HENRY WHITTINGHAM GLENDINNING, B.A. (*Cantab.*).
ERIC FINNIS JOHNSON, B.A. (*Cantab.*).
ALBERT EDWARD KENT, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
HAROLD FREDERICK LEA, Stud. Inst. C.E.
NORMAN MOORE, B.Sc. (*Cape Town*).
VELLORE MADHAVAROW MUDALIAR, B.Sc. (*Edin.*).
ROWLAND NICHOLAS, Stud. Inst. C.E.

Digitized by Google

Associate Members—continued.

JOSEPH ALFRED PARKINSON, B.A. (*Cantab.*).
JAMES JOSEPH ROUGHAN, B.E. (*National*).
LESLIE ST. CLARE RUNDLETT.
JOHN SEWELL.
RHODES MACPHERSON FOX SMITH, B.Sc. (*Cape Town*).
REGINALD WILLIAM SCOTT THOMPSON, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
ARTHUR CHARLES WEBBER, Stud. Inst. C.E.
GORDON WELCH, B Sc. (Eng.) (*Lond.*).

Associates.

KENNETH DUNDAS.
GODFREY DEAN RHODES, C.B.E., D.S.O., Major R.E.

The following Paper was submitted for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

(*Paper No. 4566.*)

"The Influence of Electric Welding in the Design and Fabrication of Plant and Structures."

By JOSEPH NEWELL REESON, M. Inst. C.E.

THE welding of joints in constructional work, whether by acetylene gas or electric arc, is still in its infancy, and the Author's experience, extending over several years, indicates that one of the reasons for the disinclination of engineers to adopt welding is that often the structures to be treated are not designed to accommodate the altered conditions. Much has yet to be learned as to the behaviour of welded joints in practical use, and such a radical alteration in the accepted method of jointing is sure to be viewed with some hesitation; but experience will gradually overcome doubts and fears, and the Author feels that the time is not far distant when electric welding will take the place of the older method of riveting in most applications. Already welding is being employed in many instances, such as boiler, tank, and structural repairs, where a few years ago it would not have been considered; but its use, judging by press accounts, is still very slight in Great Britain and in the continent of Europe, although in America and in Australia electric welding has been commonly employed in the fabrication of structures of considerable size. This Paper describes some of the work done by the Author and indicates the influence of welding on design.

The Author considers that the employment of welding in place of riveting, without due consideration being given to special design, is likely to prejudice the new method of jointing and to give rise to erroneous opinions as to the advantages of its application.

The principal doubts expressed have been with regard to:

Digitized by Google

(1) strength in actual practice; (2) the effect of corrosion on the weld and the welding deposit; and (3) the cost of welding in comparison with that of riveting, which is invariably stated to be greatly in excess.

In the course of his experience the Author has made hundreds of tests of electrically-welded joints. In every case a number of specimens, generally not less than six of each type of joint, were prepared and tested to destruction whenever the capacity of the testing-machine enabled this to be done. The object of taking such a number of examples was to eliminate the possibility of fictitious values being assigned to joints made by a particularly expert operator. It has been rightly stated that the quality of the weld depends very much on the skill of the operator, and therein lies one of the great difficulties that the engineer has to face. Where the welders are not directly under the control of the designing engineer, some doubt may reasonably be felt that the contractors' workmen may not exercise the care and skill necessary to form a satisfactory joint.

In the Author's experience much difficulty was encountered at the inception of the adoption of welding, owing to the impossibility of obtaining the services of trained welders. It was therefore necessary that the leading members of the constructional staff should familiarize themselves with the new process, and at the same time proceed to frame certain fundamental rules for the training of workmen. In 1920 the services of a skilled welder were obtained, and the general supervision of the welding was placed under his control, but with indifferent results. It then became evident that training of all the operators in the company's own workshops would have to be undertaken, and great care was exercised in the selection and subsequent training of these employees.

The operators were recruited from both the artisan and labouring classes, and the special attribute looked for was intelligence. The training of these men was no mean task and was only accomplished by very close co-operation between the staffs of the drawing-office and the workshops. It will be realized that, important as was the training of the welder to ensure an absolutely safe weld, it was still more important that the joint should be designed with as much care as would be given in the case of a riveted connection. Hundreds of tests were carried out at the testing-laboratory of the Engineering School of the University of Melbourne, on all types of welded specimens, in order that the characteristics of welds might be investigated and computed. The operators were frequently present at the testing of the specimens which they themselves had welded, and it was notable that after their first visit to the laboratory the quality

Digitized by Google

of the welds was greatly improved. As each set of test-sheets became available, they were analysed by the designing staff, and from the data obtained, fresh examples were evolved. The Company has now as full a knowledge of the requirements of a welded joint as of those of a riveted connection. The drawings issued to the shops give as much detail as would be the case were rivets being used. The size of the electrode, the number of runs, and the length of electrode to be deposited per unit length of weld are given on the drawing on which the shop and field welding is specified; which ensures the necessary quantity of metal being deposited.

A system different from that used in riveting is required for analysing the value and quantity of a welder's work, and to that end much useful information is obtainable from the welder's log-sheet, Form W1, Appendix A. The information contained in the individual welder's logs is condensed and made intelligible on Form W2, Appendix A, which acts as a valuable check on the welder's work and informs the designing staff whether their requirements are being observed. Form W3, Appendix A, is next made up, and from this the total and unit costs are obtained.

The structural-shop foreman and the foreman welder receive copies of the drawings, and the foreman welder's sole duty is to produce the most efficient welded joint. The shop foreman is not relieved of any responsibility for bad workmanship by reason of there being a foreman welder.

The initial difficulties were not confined merely to the training of the welders and the building up of the organization in the shops and in the field; there yet remained the most important factor—the designing staff. If the operation of welding were confined to general repair work, there would be little need for the designer to feel anxiety. There would likewise be little need to consider welding at all seriously if its ultimate use was to be a substitute for riveting, without regard to the more important features. There can be no comparison between a riveted joint and a welded joint as such, since welding is not a mere substitute for riveting. The economics of welding are bound up in design, and a capable designing staff may enable great savings to be effected. These economies are not obtained at the expense of the safety of the structure, for it can now be confidently expected that the joint is at least as strong as the plates or sections being joined.

Welding in the Author's practice then began to offer many interesting possibilities, as practically the whole of the usual structural workshop routine was changed. It became necessary to use jigs,

Digitized by Google

and these, together with the oxy-gas cutter and the electric welder, eliminated much work that was formerly done by the templet-maker, marker-off, punching- and shearing-machines, etc. Work began to be simplified, and the design altered with each modification—in fact, it can be stated as an axiom that with the use of welding simplification of design follows. As an instance the Author cites the construction of a steel tank 102 feet in diameter by 17 feet 6 inches deep, in which the only shop operation was to put such plates as required rolling through the rolls, the plates being used practically as they arrived from the mills.

Gasholder Construction.

The causes which led up to the adoption of welding by the Author date from 1916, when an extensive programme of gasholder construction became necessary in Melbourne. From that time onwards experiments were made with oxy-acetylene flames with varying success, the greatest difficulty being experienced in overhead welding, that is, the welding of joints so situated that the operator is underneath the work. On the 4th April, 1920, a serious collapse occurred of one of the Metropolitan Gas Company's gasholders of 3 million cubic feet capacity. In order that subsequent events may be appreciated, it is necessary to give a somewhat detailed explanation of the construction and condition of this gasholder. The structure, which was built in 1890, was of the three-lift type and was contained in a brick tank, 200 feet in diameter by 31 feet deep, situated at the South Melbourne works of the Company. The holder was about two-thirds full of gas, and collapsed without any warning. Apart from very few external patches, the sheeting was apparently in good condition, and, except for an anonymous letter forecasting the destruction, there was no direct evidence to account for the failure. The finding of a Governmental Inquiry (Appendix B) was to the effect that the collapse was due to strain caused by temperature-changes. The evidence given stated that a noise was heard resembling a gun-shot, and immediately the thin crown sheeting was ripped off close to the strong plates near the curb and folded back, the enclosed gas rising in a mass above the holder. Ignition took place, and the ball of gas burnt fiercely, high in the air, fortunately with no serious results except to the holder itself. An interesting and curious fact was that the melting of scale or rust on the metal sheets caused a shower of fused particles to be distributed over the neighbourhood. On analysis these were found to consist of magnetic iron oxide containing 72·5 per cent. of iron.

Digitized by Google

The framing of the holder was practically undamaged. After the tank had been unwatered, the collapsed material was removed; and during this operation, which occupied considerable time, the greatest care was exercised in examining the material, in order to establish the cause of the collapse. One feature impressed the Author, namely, that the fracture of the crown sheeting was not through the rivet-holes of the seams but always at the lap of the sheets, which were of iron, No. 10 B.G. ($\frac{1}{8}$ inch thick), single riveted ($\frac{3}{8}$ inch diameter, $1\frac{1}{4}$ inch pitch), with tape in seams. Extensive corrosion had taken place internally, and this was accentuated particularly at the laps of the joints, due to the bending movement and to the accumulation of moisture at this point, where the average thickness had been reduced to 0·096 inch.

The serious weakness which had arisen in the laps of the outer rows of the crown sheets indicated the defect in the design of this or of any similar holder. The crown curb of the gasholder is in effect a horizontal ring strut, strong enough to support the weight of the holder hanging from it. It has also to transmit to the crown the stresses due to the weight of the holder. The crown sheeting is in simple tension, amounting to 6,700 lbs. per linear foot. This thin sheeting, in tension, is connected directly to the curb in compression, and the change in the character of the stress apparently takes place somewhere near the junction. The crown curb and sheeting are subjected to varying stresses, according to the number of lifts hanging from the sides, and these changes may occur several times in a day; it seems reasonable to assume that such continued movement, aided by the effects of corrosion, helped to weaken the laps on this line.

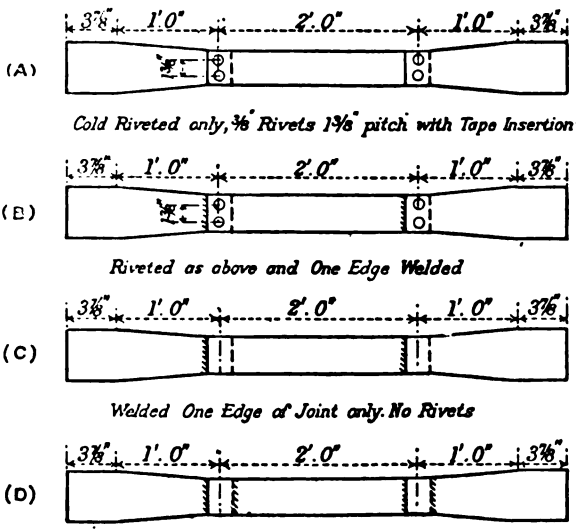
Considerable evidence of the formation of ferric-ferrocyanide (Prussian blue) was found, and the sheets were much wasted by this corrosion or by oxidation. The vertical stays of all lifts, originally none too strong, had corroded very badly, and in many cases were non-existent. This was particularly noticeable in those formed of curved plates in the inner lift. In those of the middle lift, formed of 8-inch by 3-inch channel bars, serious deformation had occurred during the descent of the holder.

The exterior of the sheets had been well preserved. The design of the structure generally was of the type usual at the period of its construction; and holders of similar design are in general use. No roof trussing had been employed, but a timber framework in the tank had been provided to support the crown when the holder was empty of gas. It is impossible to say whether the quality of the water used in the tank at some time or another had contributed to

Digitized by Google

the oxidation. A close study of the condition of the structure and the sheeting convinced the Author that the ordinary accepted practice did not allow a sufficient margin of strength, especially at the joints; with the result that he determined to endeavour at least to overcome the weakness shown in the jointing. Extensive experiments were accordingly made with electric welding on both sheets and sections, and numerous tests were conducted in the Company's workshops, and also at Melbourne University, where the Author had the advantage of the active co-operation of the Dean of the Faculty of Engineering, Professor Henry Payne, M. Inst. C.E., and of Associate-Professor W. N. Kernot, M. Inst. C.E. Both these gentlemen acted in an advisory capacity, and the Author acknowledges his indebtedness to them for their invaluable assistance. The tests were invariably made on groups of six samples, the welds being made by different operators. A typical test-sheet is shown in Table I.

Figs. 1.


(A)
3⅜" 1'.0" 2'.0" 1'.0" 3⅜"
Cold Riveted only, ⅜" Rivets 1⅛" pitch with Tape Insertion
(B)
3⅜" 1'.0" 2'.0" 1'.0" 3⅜"
Riveted as above and One Edge Welded
(C)
3⅜" 1'.0" 2'.0" 1'.0" 3⅜"
Welded One Edge of Joint only. No Rivets
(D)
3⅜" 1'.0" 2'.0" 1'.0" 3⅜"
Welded on both Edges of Joint. No Rivets

After a satisfactory tensile strength had been obtained—it being evident from the tests that the strength of a welded joint was at least equal to that of the sheet, as compared with a 55-per-cent. strength for the single-riveted joint—experiments were made to determine whether the joint was more or less subject to corrosion

Digitized by Google

than the sheet. To this end several samples were immersed in weak solutions of sulphuric acid, and sections of the weld were cut out and the surfaces were etched, polished, and photographed. The result of all these tests was so satisfactory that the Author had no hesitation in proceeding with the construction of the holder bell.

TABLE I.—ELECTRIC WELDING TESTS ON No. 10 GAUGE GASHOLDER SHEETING.

Original Dimensions.			Stress.			Efficiency of Joint at 60,000 lbs. per Sq. In. Ultimate.	Fig. No.
Breadth.	Thickness.	Area.	Yield Point.	Total.	Total per Sq. In.		
Ins.	In.	Sq. In.	Lbs.	Lbs.	Lbs.	Per Cent.	
2·797	0·132	0·3692	..	12,100	32,770	55	
2·805	0·136	0·3815	..	12,500	32,770	55	*1* A.
2·800	0·136	0·3808	..	12,750	33,480	56	
2·817	0·125	0·3521	..	16,625	47,220	79	
2·800	0·140	0·3920	..	17,350	44,260	74	*1* B.
2·771	0·138	0·3824	..	16,600	43,410	72	
2·811	0·141	0·3964	..	14,000	35,320	59	
2·787	0·133	0·3707	..	13,625	36,760	60	*1* C.
2·807	0·141	0·3958	..	13,500	34,110	57	
2·824	0·142	0·4010	20,875	24,450	60,970	100	
2·788	0·138	0·3847	19,750	23,750	61,740	100	*1* D.
2·774	0·144	0·3995	20,000	23,650	59,200	99	

The material required for the reconstruction was ordered within a few days of the collapse; and, since it had been intended to employ riveting in the new holder, difficulty was experienced in using the material to the best advantage for welding. No experience of constructing plant by welding was available, as this was the first occasion in Australia when a large structure had been so treated—in fact, the holders erected by the Author are the first of their kind in which this method has been adopted. Welders had to be trained for this particular work. Welding plant, at first using direct current from the Company's own supply of electric power, and later alternating current from the public supply, was obtained; and special plant for erecting the structure was designed in the Company's drawing-offices and constructed in the Company's workshops.

The tank of the gasholder having been cleared and repaired, the

Digitized by Google

timber framing which supported the inner lift was redesigned and rebuilt. New rest-blocks were provided for the three lifts, and the construction of the bottom curb of the outer lift was proceeded with. To ensure accuracy in the laying-out of this member and of the cups and dips of the lifts and the crown-curb, a spider's web was laid down in the construction yard and provided with a trammel of unusual design. This trammel, of 100 feet effective radius and with an equivalent working arc of 150 feet, is of the cantilever type. The main post at the centre, or point of rotation, is a 12-inch by 5-inch rolled steel joist, about 15 feet high, secured to a concrete base, back stayed, and balanced. To this main post is attached the cantilever trammel, which revolves around it. The cantilever is tapered to its extreme end and is designed with vertical members and diagonal ties in compression and in tension respectively. All members, with the exception of the main diagonals, are composed of gas tubing with reducers at the joints as required, the maximum diameter in the tension boom being $1\frac{1}{4}$ inch and in the compression boom 2 inches. The diagonals are of steel wire of suitable gauges, with turnbuckles in each length to secure correct alignment and level. The main compression boom is braced laterally with cross members of $\frac{3}{4}$-inch tubing at each panel and diagonals of 10 S.W.G. black wire.

The bottom curb, 197 feet in diameter, was constructed in suitable sections with bottom rollers attached, and was carted to the site, about 6 miles distant, where it was lowered on to the rest-blocks. Special vertical stays were then erected, consisting of three channels, one 9 inches by 3 inches and two 2 inches by 4 inches in section. Most vertical stays are inherently weak, since, owing to the necessity of leaving some clearance for the lifts to work one within the other, the space allotted to them is very constricted. The general practice is to regard these stays merely as paths for the cup guide-rollers, and this leads to weakness at a vital part. The stays should be designed as columns supporting the structure of a lift; and compliance with these conditions led to the rather unusual design which is now the standard practice of the Company. This design was used for the outer and middle lifts, but very much heavier stays were provided for the inner lift.

The side and crown sheeting was of $\frac{3}{16}$ inch in thickness, and the sheets were nominally 8 feet by 4 feet; but much larger sheets would be preferable in a welded structure. The welding of the sheets presented great difficulties, only to be appreciated by those setting out to accomplish something entirely novel; and much thought and labour were brought to bear on this important

Digitized by Google

subject. So many difficulties were encountered when the welding of the sheeting of the outer lift was commenced, that it seemed as if the task of welding such a huge area of thin sheeting into a symmetrical whole was hopeless. Most of these difficulties arose from the entire lack of knowledge then of the effects of local heating by welding, and the distortion caused by contraction was certainly unexpected.

At first, sections of four sheets, tacked together by bolts, were welded up in the shop, but on their being placed in position in the field, the distortion had altered their shape so much that it was found very difficult to join them to those already erected. New plans had to be adopted, and it was decided to erect the sheeting in place before welding. This was still unsatisfactory until special means were adopted for counteracting the contraction in situ. Close application and a determination to overcome the difficulties as they arose ultimately bore fruit; and, after weeks of experimental work, methods were devised which gave satisfactory results. The sheets were tacked together by bolts of less diameter than that of the holes, thus giving room for movement, and a framework was erected by which each horizontal ring of sheets could be strutted out to the extent of the contraction, which had become known by experience. Although this plan was satisfactory, later experience has enabled the Author to devise an entirely different method, whereby the sheets are now welded into sections at the shops.

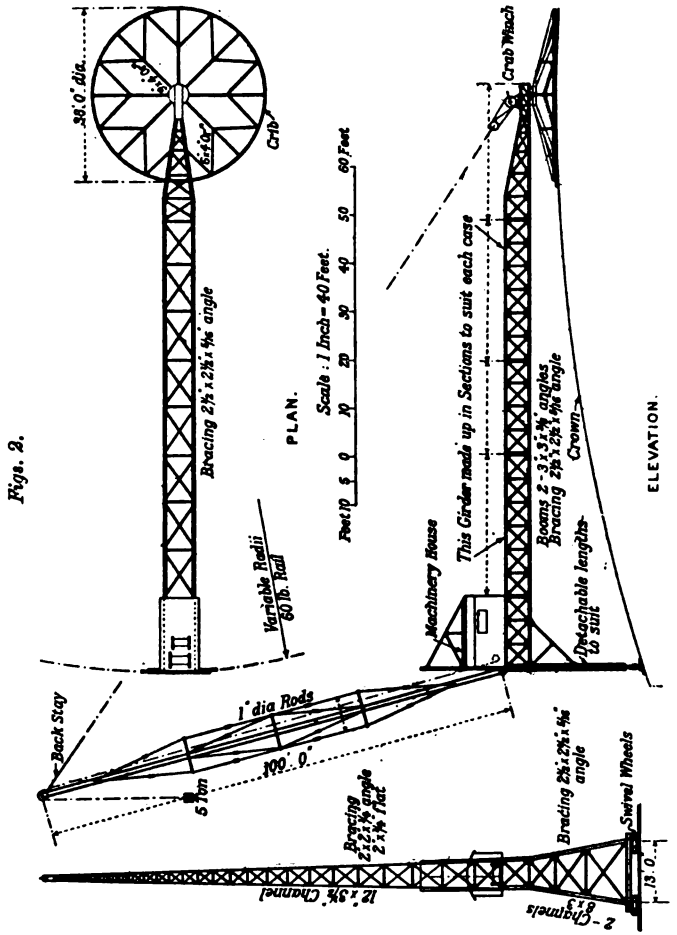
The erection of the middle and inner lifts followed closely the plan adopted for the outer lift; and although some novel features were embodied in the construction, these call for no special mention as regards welding.

The crown sheeting likewise followed the plan adopted for the side sheeting, except that it was strutted from the crown-framing The crown-curb (the outer rings of the crown) consists of strong members, the welding of which was accomplished by employing two runs of welding, such as a No. 10 electrode followed by a No. 8. No difficulty was experienced with the overhead welding of the crown-sheets.

In every case both sides of the lap were welded, although some tests which were made indicated that the welding of one side of the lap would provide a joint of greater strength than a single-riveted joint. The advantage of the welded joint in doing away with the taping is important, especially in countries subject to considerable heat and to sudden severe changes of temperature. It is within the Author's knowledge that in many cases the taping has perished, causing leakage at the seams.

Digitized by Google

In the whole length of the seams (14 or 15 miles) of this holder, less than half-a-dozen weeps were observed on their being tested by means of soap and water under air-pressure. In the erection of the holder-bell, a gantry crane revolving from the centre of the holder was employed (*Figs. 2*). This crane, which is arranged to accom-



modate structures of different diameters by varying the length of the radial arm, was designed and constructed in the Company's workshops. It was provided with jibs 50 feet and 100 feet long, and an electrically-driven winch. The centre was mounted on a timber crib, and the crane was mounted on a frame fitted with four

Digitized by Google

grooved wheels, running on a rail track around the periphery of the inner lift of the holder-bell, after the curb plates had been laid, and on the timber framing before the curb was placed in position.

The use of this crane greatly reduced the work of construction; and, as the erecting staff became expert, the great advantages of welding over riveting became apparent. As an illustration, the time taken to erect and weld the side sheeting of a lift was 28 days with 20 men, as compared with 40 days and about 30 men for a similar structure under the old conditions. The erection of the bell was completed on the 20th July, 1922. The holder has worked very satisfactorily since being put into service. Notwithstanding the early troubles encountered in welding the sheeting, the holder (Figs. 3, Plate 3) presents the appearance of a very fine piece of workmanship and certainly does not suffer by comparison with a riveted structure.

Fitzroy 2¾-Million-Cubic-Foot Holder.—A much more ambitious project was then decided upon in the design and construction of a new holder of 2¾ million cubic feet, on which electric welding would be employed exclusively. This holder was built in an existing tank of 163 feet diameter, the depth of which was increased to 36 feet by a reinforced-concrete extension. The decision to build this holder was arrived at before the South Melbourne holder collapsed, and therefore, unfortunately, the necessary material had been ordered to sizes suitable for riveting, so that it was not possible to take the fullest advantage of the economies that welding affords.

The new holder (Figs. 4, Plate 3) has four lifts each 35 feet deep, and is contained within a system of steel guide-framing consisting of sixteen steel standards 144 feet high, with five tiers of horizontal struts and diagonal wind-bracing. Generally, the details of the floating bell followed those described for the South Melbourne holder, but many novel features were added. The total weight of the holder and framing was 760 tons, and it was constructed and erected in 10 months. On completion, the holder was tested with air, and no evidence of a leak was found. The erection staff employed on this holder became so expert, that this completely electrically-welded holder and framing will bear comparison with any riveted one in existence.

Reconstruction.—Meanwhile, after the South Melbourne holder had been successfully put in service, and before work on the Fitzroy holder was started, the Author directed his attention to a small three-lift gasholder, built by the Company during 1918, the crown of which required reconstruction. The difficulty of obtaining materials during the war had necessitated the employment of some

Digitized by Google

old crown sheeting on this holder, and, when subsequently materials for the crown were obtained, it was found that the gas-storage and distribution requirements of the Company made it almost impossible to put the holder out of commission long enough to permit of the removal of the old crown and the building in of the new sheeting. The Author then conceived the idea of leaving the old sheeting in position, superimposing the new sheeting over the old crown, and welding up the whole of the material, the holder being kept in commission the whole time. This may be considered rather a bold proceeding, considering that it had never before been attempted, but the result showed that the risk was amply justified. The first operation was to weld a heavy flat on to the strong curb-plate of the crown all round the periphery of the gasholder. The $\frac{9}{64}$-inch radial sheets were cut to shape and prepared by having $\frac{9}{64}$-inch strips welded along two adjacent edges. These strips were so arranged that they were below the sheets when laid out on the crown and formed a butt strap in which the meeting edges of the next sheets rested. This butt strap protected the old sheeting below from the welding arc and also served as the medium for making the joint. This difficult and somewhat dangerous undertaking was successfully completed without the Company losing for a moment the use of this much-needed storage.

Two years later the Author decided to re-sheet the crown of a three-lift holder at the Company's West Melbourne works. In this instance the crown was about 150 feet in diameter, as against the 80 feet diameter of the Fitzroy holder. Greatly improved methods were introduced in the re-sheeting of this holder, a combination of a net having an efficiency of 50 per cent. together with $\frac{9}{64}$-inch sheeting being adopted, which design has become standard practice in the Author's Company. The net consists of a central ring, 10 feet in diameter, composed of a $6\frac{1}{2}$-inch by $\frac{1}{2}$-inch flat, an intermediate ring about 30 feet in diameter of a 36-inch by $\frac{1}{2}$-inch plate, and a ring welded round the outer strong row of the crown curb. The central and intermediate rings were connected together by sixteen 6-inch by $\frac{3}{8}$-inch flats, and the intermediate and outer rings were connected by sixteen 24-inch by $\frac{3}{8}$-inch flats. The two inner rings were not secured in any way to the old sheeting. On the completion of the net, the whole of the crown was sheeted over with $\frac{9}{64}$-inch steel sheets with lap joints, and completely welded to the net. This work was successfully completed without the gasholder being placed out of service.

This type of reconstruction would be quite impossible if riveting were to be used, as the sheeting would have to be packed up at least

Digitized by Google

2 feet from the original crown. It can well be imagined what a task it would be to lower the sheeting and remove the packing, while working over the very thin skin of sheeting composing the original crown of the holder.

While the larger jobs were being carried out, much work was being done on smaller items, such as tanks, pipes, bends, tees, elevator-buckets, bunkers, shoots, coal- and coke-trucks, etc. The shops' staffs, after overcoming the initial prejudice with which the average skilled artisan usually regards any drastic alteration in the methods he has been accustomed to employ, began to make use of the electric arc in a remarkable manner. Jigs and fixtures, which previously were costly, were cheaply built up of scrap material, and an almost uncanny skill was shown by the foremen and their assistants in applying the arc in directions not hitherto thought of. The majority of blacksmiths' work was eliminated, and it was found possible in many cases, where a casting would usually be employed, to build the article required in steel. This was especially useful when the article was urgently required, as the finished product could be produced as quickly as the pattern required for a casting could be made.

The skill shown in the shops was highly encouraging, and the best feature was that the distortion which characterized the earlier work was entirely eliminated. The knowledge gained of the behaviour of materials under welding enabled both the designing and the workshop staffs to prevent internal stresses from occurring in any of the work.

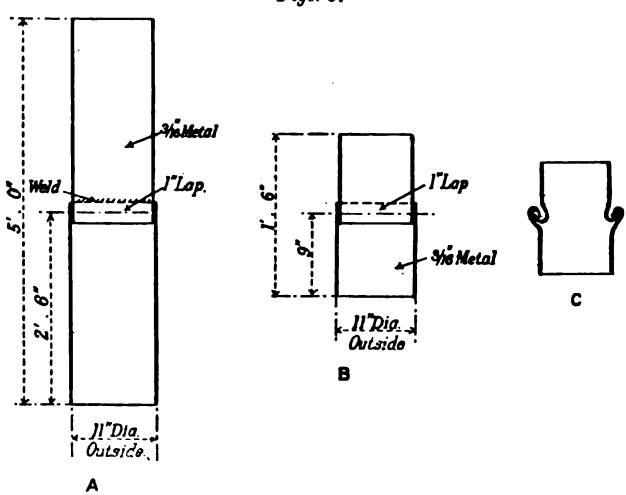
The third holder to be built at the Richmond out-station, was a single-lift type, 160 feet in diameter by 25 feet deep, with steel crown-framing. This holder had no unusual features, but it was interesting to note the rapidity of erection, which was an outcome of welding.

The fourth holder to be dealt with was at the Fitzroy station, where a single-lift holder with a capacity of 160,000 cubic feet was contained in a tank 103 feet in diameter by 23 feet deep. This was much too small for practical purposes, and the Author decided to replace it with the largest holder that could be contained on the site. To that end designs were prepared for a four-lift holder, each lift being 32 feet 6 inches deep (Figs. 5, Plate 3). It was necessary to increase the capacity of the tank by a steel-plate extension, and to alter the tank internally so as to accommodate the larger holder. A storage of nearly 1 million cubic feet was thus gained. The design of the floating bell followed largely that of the three previous holders, but contained the modifications that experience had taught. The greatest departure from present-day practice is in the guide-

Digitized by Google

framing, but, even so, this departure is only a reversion to the designs of the earliest gasholder builders. The guide-framing consists of twelve bays of standards and bracing, and five tiers of horizontal struts. The standards and struts are built of steel tubes, and the whole is so welded as to form a very stiff structure. The standards are 145 feet in length, 18 inches in diameter in the lower three tiers, and 15 inches in diameter in the two upper tiers. The struts are 15 inches in diameter in the three lower tiers and 12 inches in diameter in the two upper tiers; the metal is ¼-inch thick throughout. The economy of this construction is apparent from the weight, since there are only 125 tons of material in the whole of the guide-framing. This compares favourably with the usual latticed riveted structure, for which at least 200 to 250 tons of material

Figs. 6.



would be required. The maximum estimated stress in the framing is 10,400 lbs. per square inch, with a wind-pressure of 40 lbs. per square foot.

The cause of the Author's adoption of this form of standard and strut is interesting. A number of 12-inch diameter steel pipes about 32 feet long had been welded up, and their appearance of strength so impressed the Author that it was decided to use some of this pipe in the construction of a 6-ton 50-foot jib for a Scotch derrick crane. Before building the jib, however, four test lengths of pipe were prepared in order that the behaviour of the welded strut could be observed. Each piece was formed of an exterior and an interior pipe, lapped in the centre and welded on one side of the lap only; the

Digitized by Google

longitudinal seam was butt welded, the whole following the general practice of pipe-manufacture (*Fig. 6* A).

The full load of the testing-machine (110,000 lbs.) was applied, with no observable results. The pipes were then shortened (*Fig. 6* B) and placed in the accumulator press of the testing-machine, where 280,000 lbs. was applied. No results were observable there, and the pipes were taken back to the construction workshop. The works' hydraulic press was then calibrated, and the specimens were put into compression again, when failure occurred at just over 400,000 lbs. by the pieces of pipe telescoping one within the other (*Fig. 6* C). It is a significant fact that, after partial collapse, the pieces were removed, and on applying air-pressure of 50 lbs. per square inch, the welds were found to be perfectly sound. From this it appears abundantly clear that the designer, after computing the stresses and providing sufficient material to resist them, can rest assured that a full-strength weld will be at least as strong as the sections he desires to unite. A test was designed for a circular column section 28 feet in length, equal to the depth of a tier of bracing. The worst conditions to which a column is subjected during a heavy gale are caused by the weight of the material above the section in question, the stresses due to the vertical component of the wind load, the horizontal thrust from a radial roller, and the torsional effect due to the pressure from a tangential roller. The maximum direct compression in the standard occurs when the roller load is purely tangential, and hence this condition was reproduced in the tests. The worst conditions as calculated showed the value of the tangential roller load to be 6,400 lbs., acting at a distance of 16 feet 5 inches from the centre-line of the standard, and the direct compression to be 54,000 lbs. To reproduce these conditions in the workshop, a testing-plant was constructed, consisting of four bars, along which three grills were placed (*Figs. 7*). Between two of the grills the 28-foot length of standard under test was placed and welded into position. Between the second and third grills was placed a flexible steel bladder, filled with water and connected to a pump and gauge. The required direct compression was obtained by raising the pressure in the bladder, and its value was determined by measuring the extension of a 22-foot length marked off on each of the top tie-bars. The equivalent torsional effect was obtained by applying a load of 1 ton at a distance of 8 feet from the centre-line of the standard and placing a load of 2 tons directly over the standard. The torsional deflection was noted by means of a straight 12-foot beam projecting 6 feet each side of the centre-line of the standard.

Digitized by Google

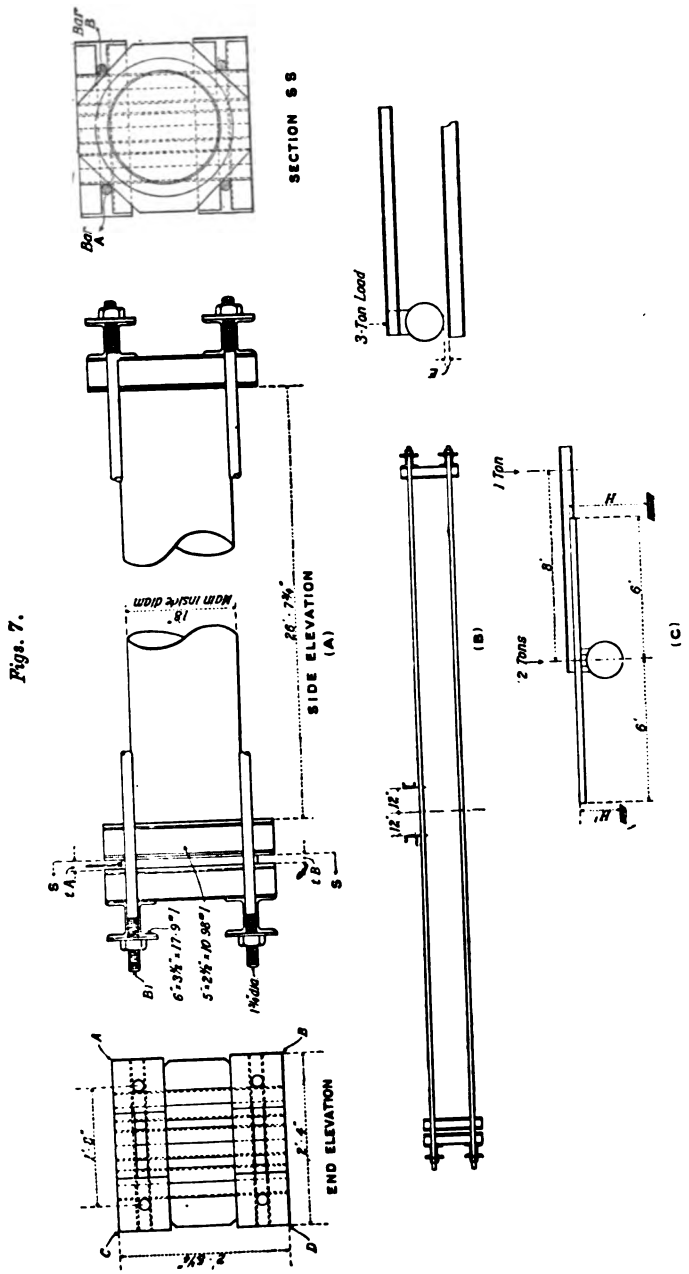


Fig. 7.

Digitized by Google

Tables II, III, and IV show results of the tests, the maximum pressures being those at which the bladder failed:—

TABLE II.—DIRECT COMPRESSION (*Figs. 7A*).

Pressure in Bladder.	Elongation on 20-ft. Length of Tie Bar.		Distances between Plates at Edge of Bladder at Points A, B, C, D.				Load on Column calculated from observed Elongations.
Lbs. per Sq. In.	Inch.		Inches.				Lbs.
			A	B	C	D	
0	..	..	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{5}{16}$	$2\frac{3}{8}$	..
150	..	..	$2\frac{3}{8}$	$2\frac{5}{16}$	$2\frac{1}{8}$	$2\frac{1}{8}$	..
300	..	..	$2\frac{7}{16}$	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{9}{16}$	..
400	..	..	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{11}{16}$	$2\frac{11}{16}$	..
500	$\frac{7}{64}$	$\frac{19}{64}$	$2\frac{19}{32}$	$2\frac{19}{32}$	$2\frac{11}{16}$	$2\frac{11}{16}$	146,500
550	$\frac{9}{64}$	$\frac{13}{64}$	..	..	..	..	185,500

TABLE III.—DIRECT COMPRESSION AND BENDING (*Figs. 7B*).

Pressure in Bladder.	Bending Load.	Distance *E*.	Distance between Plates.			
Lbs. per Sq. In.	Tons.	Inches.	Inches.			
			A	B	C	D
500	0	$2\frac{1}{16}$	$2\frac{19}{32}$	$2\frac{19}{32}$	$2\frac{11}{16}$	$2\frac{11}{16}$
500	3	$1\frac{11}{16}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{3}{4}$	$2\frac{11}{16}$

TABLE IV.—DIRECT COMPRESSION, TORSION, AND BENDING (*Fig. 7C*).

Load.	Deflection at H.	Deflection at H'.
Tons.	Inch.	Inch.
3	$1\frac{1}{2}$	$1\frac{1}{2}$

Bar.	Maximum observed Extension.	Calculated Direct Compressive Load.
	Inch.	Lbs.
A	$\frac{3}{16}$	294,500
B	$\frac{3}{16}$	

Owing to the curvature of the column under direct compressive and bending loads, there was a shortening of 0·104 inch on the 22-foot lengths of the two top bars. Hence the total extension of each of the top bars over a 22-foot gauge-length = 0·1875 + 0·104

Digitized by Google

= 0·2915 inch. The area of each bar is 2·405 square inches, hence the load causing this elongation is 73,625 lbs. per bar, equivalent to a total direct compressive load on the standard of 294,500 lbs., which is greater than four times the calculated maximum direct compressive stress which the column would carry in practice. The calculated maximum extreme fibre stress during this test was 30,380 lbs. per square inch.

No evidence was discernible in the column itself of the effect of the load—in fact the slag covering of the welds was not disturbed.

Various Applications.

Among other interesting examples of welded construction may be instanced the No. 4 continuous vertical retort-house at the Company's West Melbourne works. This house afforded an excellent opportunity for reviewing the design of the conventional steel structure. The whole of the columns, struts, beams, roof-trusses, and conveyor-tracks, together with the steel chimneys, 5 feet in diameter by 120 feet high, and a set of overhead coal-bunkers designed to hold 700 tons, were welded, the total weight of the steelwork being about 400 tons. A further retort installation of the same type is now in course of construction, and many changes are being made in design in order that the ultimate value of the process may be realized.

Perhaps one of the most striking instances of the value of electric-arc welding to the engineer who has much valuable plant under his charge occurred on the afternoon of the 21st March, 1924, at the Company's North Melbourne out-station. The gasholder inspection-gang was engaged in bolting a small patch plate on the side of the inner lift of the 3 million-cubic-foot holder, which was inflated to a height of about 50 feet and contained 1,500,000 cubic feet of gas. By some extraordinary mischance the gas became ignited at the place where the men were working, and, as they failed to extinguish the flames, the heat rapidly distorted the sheeting and opened up the seams for some distance. The flames burnt with such fierceness that the fire brigade were unable to extinguish the fire, which continued until the holder had lowered itself sufficiently to submerge the rent seams.

The first and immediate need was to arrange the distribution of gas so that the public should suffer as little inconvenience as possible, and it was not until the 25th March that the Author was able to give his attention to the matter of repairing and recommissioning the holder. It was plainly evident that nothing could be done to the inner lift, which was floating about 6 or 7 feet out of the water,

Digitized by Google

greatly out of level. As this storage was of great importance in the gas-distributing system of the northern districts, no time could be lost in repairing the holder. The Author therefore decided to couple the inner and middle lifts together, since the curb and crown of the inner lift were undamaged, the sides only having suffered.

As the weight to be lifted was estimated to be about 200 tons, a sample hook was made of 4 inches by ½ inch flat, reinforced at the bend, and tested at the University. It withstood a load of 25 tons, which was well within the requirements. Seventy-two hooks were then made and spaced equidistantly around the periphery of the holder. The lower ends were hooked under the dip plate of the middle lift and the upper ends welded to the top curb of the inner lift. An important problem was to get all the hooks into even bearing. Careful preparations were made, and a gang of six welders commenced early on the morning of the 27th March, the holder being watched carefully so that, as the hooks were placed in position, it did not drop, but rather was elevated very slightly. All the hooks were completely welded in position in the one day, and then the holder was inflated for a further 2 feet with the middle lift suspended. Curved sheets were then welded on, covering the space between the lifts. This operation took 3 days and was completed on the night of the 13th April. Gas was admitted to the holder on the 14th April, and it has been working satisfactorily since. The holder therefore, was 3 weeks out of action, and the time would have been shorter still but for delay in obtaining electric current from the city authorities.

Unfortunate as this occurrence was, it would probably have been worse, and might in fact have paralleled the South Melbourne collapse, had not the crown of the holder been strengthened 2 years previously by a reinforcing net. This net undoubtedly prevented the crown sheeting from splitting at the seams near the point of conflagration, and folding back, with the inevitable wrecking of the whole structure.

As the crown of any gasholder is the most vulnerable part, the Author spent considerable time in studying the best means of protecting those holders under his care. To that end a method of design was evolved which has been applied to three of the older of the Company's gasholders. Briefly it consists of a number of circumferential rings connected together by radial bars, the whole lying loosely on the crown sheeting except at the outer ends of the outer radial bars. These are welded down to the crown curb, and the sheeting is thus enclosed in a steel net. Simply enclosing the sheeting is not enough; the net must also relieve the sheeting of

Digitized by Google

a great deal of its stress, and it was designed to take two-thirds of the load. This net was constructed of four rings of 12-inch by $\frac{3}{8}$-inch steel flats connected through 3-inch by $\frac{3}{8}$-inch flat steel radial bars. The outer row of radials had a coupling-screw in each bar, and on the completion of the net the whole was stressed to a predetermined limit, by the use of an extensometer.

Simultaneous with the progress made in the building of gasholders and other large structures was the advance made in the design of other gasworks plant. Among some of the other plant that has been constructed may be mentioned a set of purifiers of 3-million cubic feet capacity. These consist of four boxes set in a square, the main overall dimensions being 76 feet long, 50 feet wide, by 6 feet deep, each individual box being 38 feet by 25 feet. The total weight of steelwork, including superstructure and lifting-gear, etc., was 150 tons. These purifiers cost about £13,000, which includes the piled foundations, of 80-foot piles, concrete floors for oxide revivification, mains, purifier-grids, and lifting-apparatus complete. This cost compares favourably with £22,500 paid for a 3-million-cubic-foot set of the usual cast-iron pattern erected 4 to 5 years previously. Since the erection of this plant, welded-steel purifiers have been advertised by American manufacturers.

Water-tube condensers, tar-extractors, ammoniacal liquor concentrating-plant, liquid flotation purification-plant, steel chimneys, etc., are now all being carried out in welded steelwork.

The concluding example of work done was the building of a combined gas-main and foot-bridge. It was necessary to lay a main from the Company's Tooronga station to the Glen Iris district, and, as the shortest route was over Gardiner's creek and through a public reserve, the Council, in giving its approval of the route, stipulated that a foot-bridge over the creek should be provided, so as to give access to public land on the other side. The Author proposed to combine the main with the foot-bridge, so the design provided for a 24-inch welded steel main, of $\frac{1}{4}$-inch plate, 90 feet long. The main was cambered and was carried by two steel cradle piers in which it was securely welded, forming a fixed beam with cantilever ends. Brackets were welded in to carry the timber decking and hand-railing, thus giving a gangway 40 feet long. This bridge was built well above the highest recorded flood-level of the past 30 years, but it had not been in use more than a few months before it was subjected to a very heavy flood. At one period only the upper 18 inches of hand-railing was visible above the water, which was running at 8 to 10 miles per hour. During this flood the bridge was subjected to heavy blows from floating timber, and the accumulation of debris against the

Digitized by Google

pipe and the decking offered considerable resistance to the flow of the water. Examination, after the subsidence of the flood, disclosed no damage whatever; none of the seams was at all strained, and there was not the slightest sign of any leakage of gas. The bridge has since withstood without damage the effects of two other floods.

The Author has endeavoured to indicate some of the ways in which welding has been adopted under his direction, and he would emphasize the fact that in his experience of the subject (during which 2,000 tons of material annually has been fabricated in the Company's workshops), welding offers, firstly, much greater security than riveting, and secondly, such remarkable simplification of design in the office and such great economies in the field and workshop that it is surprising it has not been employed to a greater extent than has been the case. Outstanding points from his experience in welding are summarized in Appendix C.

In conclusion he desires to place on record his appreciation of the assistance he has had from the Designing Staff, Workshop Department, and especially from his assistants, Messrs. R. J. Bennie and H. E. Grove, to the latter of whom is due much of the credit for the success achieved in the development of electric welding.

The Paper is accompanied by three tracings and two prints, from some of which Plate 3 and the Figures in the text have been prepared, by the following Appendixes, and by a book of photographs.

[APPENDIXES.

Digitized by Google

APPENDIX A.

FORM W. 1.

MACHINE NO. ..... DESCRIPTION A.C. / D.C. WELDER .....

CLASS OF WELD { O. = Overhead. H.O. = Horizontal Overhead. H.D. = Horizontal Downward. V. = Vertical.

RUNS { Class as 1st, 2nd, 3rd, 4th, etc.

Year..... Month. Day.	Electrodes Used. No.	Feet.	Description.	Hours Welding.	Hours not Welding. No.	Reasons.	Class of Weld.	Run.	Feet Welded.	Feet of Electrode per Ft. of Run.	Feet Run per Hour.	Average Amperage.	Job. No.	Description of Work Done.	State: i. Location. ii. Thickness joined. iii. Butt—Fillet —Tack.	Remarks.

FORM W.2.

METROPOLITAN GAS COY. WELDING REPORT AND EXAMINATION SHEET.

Week Ending .....

Welder.	Machine.	Amperage.	Job. No.	Description.	Electrode.	Run.	Class of Weld.	Actual Deposit Electrode Per Foot.	Inches Weld Per Stick.	Feet Per Hour.	Total Hours Not Welding.	Remarks.

FORM W.3.

CONSTRUCTION DEPT. WELDING LOG.

Week Ending .....

Job No.	Particulars of Work.	Total Feet Welded. Single Run.	Total Feet Electrode Consumed.	Labour Costs. Chipping and Assembling.	Welding.	Total. Labour (A)	Electrode Cost (B).	Combined Total A/B	Unit Cost Foot-Run. Pence. Labour.	Electrode.	Total.	Remarks.

Digitized by Google

APPENDIX B.

Finding of the Board ordered to inquire into the collapse of a gasholder of the Metropolitan Gas Company.—We find, as the result of our inquiry, that the destruction of the gasholder was due to the breakage of the cup of the middle lift and that this breakage was the result of temperature stresses, for which provision had not been made in the design of the gasholder. We find also that the holder had been considerably weakened, mainly by internal corrosion, during ts 30 years' service, and that this was a contributing cause.

APPENDIX C.

Salient Points on Electric-Arc Welding.

Design.—The designer is free from the limitations imposed by rivets. He has a medium that will ensure 100 per cent. strength at the joints. Whereas rivet-holes weaken a section, the weld adds strength.

Detail.—The detail draughtsman's work is much simplified, the laborious work of calculating for hundreds of rivet-holes is reduced, and the liability of error in spacing holes is minimized by the fact that few, if any, holes are needed. Drawings therefore, pass through the office more expeditiously.

Fabrication.—The high degree of accuracy necessary to ensure rivet-holes matching each other in a big structure is not required in welding. The templet-maker's duties are reduced considerably—shearing, punching and drilling work in welding may be only 25 per cent. of that necessary in riveting, and may be dispensed with altogether in many cases. Forgings, in many instances, may be more easily and cheaply replaced by the welded substitute. In addition to the labour saved, the overhead burden is reduced.

Despatch.—Welding simplifies stores despatch as, generally, two sizes only of electrodes replace the great varieties of rivets required in erection.

Erection.—With the electric-arc and the oxy-acetylene flame the erection in the field has practically all the advantages of a workshop. Alterations or additions are easily accomplished.

Generally.—Where ordinarily castings are required they may be replaced advantageously by welded articles built out of scrap material, which offer great possibilities, and may be as easily constructed in the field as in the shop.

Repairs, Alterations, and Emergency Work.—Welding, in repair work, occupies a most important position—not the least advantage being that repairs or alterations can be effected without dismantling plant, and, in some cases, without stopping its operation.

Digitized by Google

Discussion.

The President.

The PRESIDENT, in moving the vote of thanks to the Author, referred to one of the earlier applications of electric welding which had brought about a change of method in this country. About 15 years ago he had been faced with the problem of producing the large turbine-drums of the S.S. "Carmania," and had solved it by the use of electric welding, which was in those days a little-known art. It had not proved very difficult to obtain a perfectly sound weld; the difficulty had been rather to ensure perfect physical solidity on each side of the weld. The physical strength of the welded portion could therefore not be regarded as being the true physical strength of the whole drum. Another difficulty, which had been surmounted, though not very easily, had arisen during the cutting of the grooves for fitting in the blading—there were over 10,000 blades on one drum. Also, caulking of the blading at each side of the weld had been a matter of some considerable difficulty. He mentioned that as an interesting point of history in connection with electric welding, because it was that difficulty which had caused hollow rolling to be introduced, and during the war every drum for turbine work had been hollow-rolled instead of welded. These remarks referred to the welding of thick articles, the drums in question being 1¾ inch thick. He was quite aware that the welding of thin articles, such as the Author dealt with, was a very different problem. He could not help feeling that electric welding suffered from a little prejudice, because it had been primarily introduced for the purpose of repair, and it was not always used judiciously in that connection. Taking, for instance, the case of steel castings which were not quite satisfactory, there was no possible objection to applying electric welding for the purpose of repair if it was done under very strict supervision; but unless the whole of the defect —whether unsoundness or the effect of contraction—was absolutely removed before welding, the welding covered up unsatisfactory work. There was no doubt whatever that among engineers electric welding was not regarded with very great favour. That had probably stood to some extent in the way of the introduction of electric welding for new work. The Author dealt with very light structures, and it appeared that he was not relying on the ultimate tensile strength of the weld being equivalent to the original tensile strength

Digitized by Google

The President. of the steel, but regarded it as being at least equal to the strength of a riveted joint. The President could not help thinking that the element of stiffness which a riveted gasholder possessed must in itself be of some slight advantage, especially for avoiding buckling in erection, as well as to some extent for permanent strength. The Author had certainly put before the members a wider application of electric welding than they had had in their minds previously, and for that reason he had done service to The Institution. He had shown that it might safely be applied to new structures on a very large scale, and he had given them information which could not fail to help them in their work in that direction. The President saw at once one direction in which electric welding might be applied. The roofs of blast-furnace gas-heating stoves were very troublesome from a repair point of view, being very light structures; and the removal of the whole of the roof and rebending and fitting it was a long and costly matter. If it were possible to adopt electric welding in that connection, he thought blast-furnace managers and engineers would welcome it.

Mr. Botley. Mr. C. E. Botley considered that all gas-engineers would peruse the Paper with great interest, and with advantage. Electric welding was commonly employed in gasworks, though possibly it was more used in connection with repair work, such as the repair of cast iron, and temporary repairs of boilers, especially in an emergency. It was also used for special high-pressure steel mains, which were coming very much to the fore in connection with high-pressure gas-distribution. He thought the Author rightly said that nothing had been done in this country on such an extensive scale as in Australia. The repair of a gasholder in the ordinary way by means of electric welding was an extremely dangerous operation. The Author, with the thoroughness which characterized engineers in the Dominions, where necessity was very often the mother of invention, had foreseen the difficulties, and his application of electric welding to the renewal of the crown of a holder was both ingenious and convincing. The electric welding of thin sheets, unless the operator was very experienced, more often resulted in a hole than in a weld. The method which the Author had adopted in repairing the crown of the holder was the introduction, while the gas was in the holder, of a metal net over the crown, so arranged that there was something underneath the joint which would be impervious to the penetration of the flame. The Author had been very successful in training a number of welders, which was one of the most important matters. It was astonishing how expert the men eventually became; but they required sound training. The Author made out a case for

Digitized by Google

electric welding on the point of cost, but Mr. Botley's experience was that the electrodes were expensive; and he would hesitate to depart from established practice without some convincing proof that economy would result. In the absence of further proof, he would rather hesitate to accept the Author's explanation of the cause of the failure of one of the South Melbourne holders. The Author attributed the defect to temperature-stresses, but, having seen the lantern-slide exhibited, Mr. Botley was of the opinion that it was more probably due to internal corrosion. From the programme of repairs which the Author set out, it would appear that the conditions in Melbourne were quite exceptional, with regard to either the original construction of the gasholders or their deterioration. Certainly a very serious problem of reconstruction had had to be faced. The description in the Paper of the ingenious method of coupling the middle and inner lifts together had puzzled him a great deal, and even after having seen the slides he was not quite clear as to how it had been done. But the point was that the Author had brought electric welding to such a successful pitch that he had been able to put into service a badly damaged holder in a minimum of time and doubtless at a minimum of expense. Mr. Botley.

Mr. T. M. AITKEN remarked that for many years he had taken an interest in welding in this country, but he was afraid that no welded structures had been undertaken comparable in size with the Author's work in Australia. However, in spite of that fact, a few interesting applications had been made in this country. About 6 years ago the firm with which he was connected, the Anglo-Swedish Electric Welding Company, had been entrusted, after very careful tests in the first place, with the welding of most of the joints of a large marine boiler, designed and constructed by Messrs. R. & W. Hawthorn, Leslie & Company. The diameter was 15 feet 6 inches, and the boiler was of the usual marine type with three internal furnaces. It was constructed for 180 lbs. per square inch working-pressure, the shell plates being $1\frac{1}{4}$ inch, and the end plates $1\frac{5}{16}$ inch thick. The end plates, instead of being flanged and riveted to the shell, were simply plain disks put into a small groove planed in the shell plates before they were put through the rolls. After erection, a line of fillet welding had been run from the outside and the inside. That was the only joint between the end plates and the shell. The joints in the combustion-chambers were all welded. There was no double thickness and there were no rivet-heads, which, of course, was a great advantage. No leak had been observed even on the first testing of the boiler at 360 lbs. per square inch. That boiler had now been working for 6 years under trying conditions with oil Mr. Aitken.

Digitized by Google

Mr. Aitken. fuel and forced draught, and it had never shown the slightest weakness. A design of that description offered very great advantages. To flange, level, and anneal plates 16 feet in diameter and $1\frac{5}{16}$ inch thick was a difficult and expensive operation, and he believed that about 20 tons of fuel were required for the work on a boiler of that size. The drilling for this joint required 290 holes at each end, making 580 holes in all, $1\frac{5}{16}$ inch diameter, through a double thickness of plate of more than $2\frac{1}{2}$ inches. Thus there was considerable saving in the welding process. Referring to the Author's comparison between riveted and welded joints, Mr. Aitken cited some tests carried out a few years ago on plates $1\frac{1}{4}$ inch thick. A treble-riveted butt-strap joint used in a certain structure had been very severely stressed, and his firm had been asked whether there was likely to be an improvement if the joint were welded in addition to being riveted. When they expressed themselves as quite confident about the superiority of the welded joint, they were invited to prove it. Test-pieces were made of 24–28-ton steel exactly similar to the part of the structure in question, some being riveted only, and others riveted and welded; they were sent to Professor B. P. Haigh, M. Inst. C.E., of the Royal Naval College, Greenwich, for testing. Professor Haigh designed a special extensometer to check not only the extension of the pieces but also the lateral deflection, the main object being to find what load the joint would take without showing any permanent set. Professor Haigh therefore subjected the pieces to small increments of load of about 2 tons each, each additional load being taken off and measurements taken to see how the joint as a whole had been affected in its elastic properties. The results showed that the riveted specimen took a permanent set at a total load of $12\frac{1}{2}$ tons (corresponding to 2·8 tons per square inch net area of plate), whereas a specimen of the same dimensions which had been welded in addition to being riveted took 60 tons load (corresponding to about 13·3 tons per square inch net area of plate) without any permanent set whatever, and any load beyond 60 tons would have been in the neighbourhood of the elastic limit of the plate itself. Upon those tests Professor Haigh reported that the welded joint was certainly about four times as strong as the riveted joint. Results of that kind indicated that there appeared to be no question that in due course the riveted joint would be replaced altogether by the welded joint.

Mr. Plumstead. Mr. A. E. PLUMSTEAD observed that the Author stated that electric welding was in its infancy, especially for constructional work. That no doubt was quite true, for the English manufacturer was rather slow to adopt new methods of construction. It might

Digitized by Google

perhaps be due partly to the fact that he had been more or less "sold" on more than one occasion by an incompetent welder, because in the early days of welding much inferior work had been done, and the progress of the welding trade had been retarded thereby. Another reason might be, as a previous speaker had pointed out, the high cost of the best brands of electrodes. The Paper was of real value to welding engineers, who, he thought, should be more persistent in bringing to the knowledge of general engineers the great possibilities of welding. In that respect they should make a strong point of impressing upon engineering manufacturers the desirability of closer co-operation between the designer and the welder. Designers were rather too apt to design their work without due regard to the welding. By closer co-operation with the welder they would be able to obtain greater simplicity in design and more economical results. The Author did not give the relative costs of a riveted gasholder and a welded gasholder. Cost was of primary importance to engineers, and he thought that the Author could make out a case for cheaper construction by electric welding, with an important saving in time also. With regard to the collapsed crown of the gasholder at South Melbourne, he asked what the Author considered to be the cause of the internal corrosion—whether it was really a result of the stress caused by the movement of the plates due to varying temperatures, to the difference in the thickness of the crown-plate and the curb-plate, or even perhaps to inequalities in the manufacture of the plates, or whether it was due to chemical action from the moisture in the gasholder. He would also like to know the Author's view as to the cause of the gas igniting after the crown had collapsed. Further, he would appreciate information as to whether pure-iron or mild-steel plates were better for gasholder construction by welding. A little more detail regarding the welding itself would have been acceptable, as well as some explanation as to how allowance was made for contraction effects in the weld. Some of the plates were probably 6 to 8 feet by 4 feet, so that considerable contraction would take place in the weld after proceeding, say, half-way towards the end of the plate. He had in mind the probability of the invention of a portable seam-welder. If such a thing could be devised, it would appear to him to afford a solution of the problem of welding $\frac{1}{2}$-inch steel plates, especially in the construction work of a gasholder. The Author described (p. 169) the reconstruction of a gasholder in which new sheeting was superimposed over the old crown and the whole material welded together, the gasholder remaining in service the whole time. That was, as the Author claimed, a bold experiment, but Mr. Plumstead, if he might say so, had carried out a bolder experiment

Mr. Plumstead

Mr. Plumstead. in making repairs to a large gasholder where there was more danger in doing the work. Mr. Thomas Glover, M. Inst. C.E., had been in difficulty with regard to a gasholder of 800,000 cubic feet capacity at Norwich, the plates of which had suffered from serious external corrosion. Curiously enough, the corrosion had only affected some of the plates; that was to say, there was one bad plate, or a group of two or three bad plates, between plates which were in perfect condition. The gasholder was 33 years old, and he was unable to say whether the plates were of iron or steel. The method of repairing that gasholder differed from that described in the Paper. The Author had put a steel network over the gasholder and welded the plates together separately from the crown of the gasholder, making the joint between the new and old crowns on the curb-plate, which was perhaps $\frac{3}{8}$ inch thick. In the case of the Norwich gasholder, however, the repair had been carried out by welding $\frac{1}{8}$-inch steel plates with a lap weld over the actual defective original $\frac{1}{4}$-inch plates. About 120 new plates had been put on the crown and sides of the gasholder while it was actually in use. During the repair, leakages had had to be contended with. Bolts and fish-plates had had to be removed from the top of the gasholder, leaving holes up to $\frac{3}{4}$ inch in diameter; and steel washers had been pressed on over the holes and welded round before putting the new sheet on over the old one. The repairs had been effected in about 3 months, and had proved perfectly satisfactory in every way. Probably the Author would not in future, when he had damaged side sheets in a gasholder, weld the upper and lower lifts together and thereby reduce the storage-capacity of the gasholder, but would weld new plates on the outside and thus maintain the whole of the storage-capacity. He must confess he could not quite see the advantage of the radial-bar system of strengthening the crown (p. 176), because the radial bars apparently were only fixed on the curb-plate and at the centre. It appeared to him that they should have been lap-welded, or fixed in some way to the crown of the gasholder. Even if any strength were obtained by that method, he imagined there must be disadvantages, inasmuch as a great deal of corrosion would be set up between the radial bars and the crown-plates, and there would be cavities for the accumulation of dirt and moisture, which would be detrimental to the roof of the gasholder: and there would probably also be some friction, due to expansion and contraction, between the radial bars and the crown plate. The President had expressed some doubt as to the strength of thin plates—say $\frac{1}{8}$ inch thick—on each side of a welded joint. During the repair of

Digitized by Google

the gasholder to which Mr. Plumstead had referred, samples of the welds had been taken haphazard and sent to a laboratory for testing. The report on the results of those tests had been to the effect that the strength of a single-lap-weld joint, taken at random from the various pieces of welded material lying about, was 97·9 per cent. of the strength of the original plate—more than 20 tons per square inch. It was therefore quite evident that a good strength could be obtained by electric welding. Mr. Plumstead

Professor W. E. DALBY remarked that the Paper showed it was quite possible that engineers might look to wide applications and wide extensions of the process of welding. He could recall some special classes of welding on machine parts and so on, but this was the first time he had had definite information as to welding on such an elaborate scale. There were, however, questions which would have to be settled before constructional engineers could be convinced of the desirability of the general application of the method of electric welding, and that was, the effect of electric welding upon the elastic properties of steel or iron. He remembered an electric welding machine being introduced a good many years ago into Crewe works, when there was a proposal to weld lap joints of boilers, etc.; but it was found that a lap-welded plate, although quite as strong as the original plate, had lost its peculiar elastic property, and 30-ton steel was somewhat hard and brittle around the region of the weld. Whether that difficulty had been overcome or not he did not know, but that was a point about which engineers would have to be convinced. The Paper contained references to, and examples of, numerous tests which had been carried out on electrically-welded joints, but a statement of the ultimate strength of a welded joint, as given on p. 164, was not enough to satisfy engineers that it was safe to use it in general constructional work. Ductility might be lost, the metal might be hardened, and its property of standing alternating loads might be destroyed. Those were points which would have to be answered before electric welding made rapid strides among engineers. Mr. Aitken had referred to a boiler which had been constructed by electric welding. Professor Dalby would like to know a little more about the processes of annealing applied to the plates after welding. In his experience of electric welding at Crewe it had not been possible to get, after electric welding, uniformity of the material across the weld. Gasholder construction was an exceptional application of electric welding, because the hardening of the metal did not matter quite so much in that case. Professor Dalby.

Mr. AITKEN stated that no annealing whatever had been done in connection with the boiler to which he had referred. Mr. Aitken.

Digitized by Google

Correspondence.

Mr. Anderson. Mr. J. T. Noble Anderson observed that it was not often that the opportunity and the man were so well fitted for success as in the case of the Author's introduction of this method to the large works of his Company. The Paper was of great value as recording what was probably the largest extension in recent years of this method of joining up work. He regretted, however, that references were so brief and contained so few details. No doubt, the Author, with his usual modesty, had left information to be supplied by his associates. In completer form the record would be a classic to be used by those who should follow in his footsteps. In the meantime, the Paper was all the more convincing because the Author told so clearly what actually happened. Mr. Anderson had had opportunity of knowing intimately some of the triumphs of this method under the Author's control, and he could only speak with admiration of the expedition, facility, and economy with which the work had been carried out. The task of renewing worn-out gasholders and works supplying a population of nearly a million inhabitants had seemed insuperable, but the result had been achieved so expeditiously, and the organization has worked so smoothly, that the people of Melbourne had not been aware of the dangers and difficulties surmounted. The most notable achievement was the fact that the work had been carried out by day-labour methods and without the intervention of a contractor. He had on more than one occasion called for tenders for bridges and waterworks, hoping that the cheapness and facility which electric welding would give would result in low prices; but entirely without success. There was a common belief that day-labour work in Australia was exceedingly expensive; but the fact that Australian workmen, when the work was properly organized, would work for a large Corporation or the Government just as efficiently as for a contractor, had been proved by the works which the Author had carried out. Had the work been carried out by a patentee and capitalist working for personal gain, more care and attention could not have been bestowed, in evolving suitable plant, establishing reliable organization, and testing each step, than had been the case with this work, carried out by engineers who had no pecuniary interest in its success. What had been done by them was now being done by bridge-engineers and others in Australia, in fields

Digitized by Google

where electrical welding was novel, with the happiest results. Engineers who had become accustomed to the appearance of almost rivetless structures were beginning to realize what a retrograde step it would be to return to the old riveting system; and, thanks to this innovation, many important public works were carried out in these days of expensive labour and capital just as cheaply as they had been in pre-war days. Mr. Anderson.

Major JAMES CALDWELL remarked that the Paper would be a valuable guide to those interested in electrically welded construction, and it was particularly instructive because of the magnitude of the structures described. The Author rightly emphasized the fact that manufacturers and erectors of steel structures who decided to use electric welding were able to save material, owing to the greater strength and simplicity of joints; and to secure full advantage they must therefore modify the recognized principles of design as applied to riveted work. This, and the assembly of parts during erection, together with the closing of plate-seams preparatory to welding, with provision for expansion and contraction strains, constituted the main problems which called for the attention of engineers responsible for such undertakings. Major Caldwell.

The satisfactory results obtained by the Author showed that he had succeeded in overcoming these difficulties of welded construction in relation to the manufacture of gasholders, just as the pipe- and tank-maker and the shipbuilder must deal with their particular applications in their own way. Those who had specialized in developing the electric welding process had provided suitable plant, apparatus, and materials, and had carried out repairs and new construction sufficient to prove reliability and endurance. Unfortunately many of the pioneer undertakings had not been carried out under ideal conditions for ensuring economy, but he had never known an electrically-welded structure fail to fulfil the conditions for which it was designed, and the wear and tear of practical use. Until, however, it was generally recognized that electric welding consistently provided reliable joints, there was considerable anxiety in case failure should occur, and in order to prevent probable collapse it was frequently proposed to provide wider plate overlaps and butt straps, sufficient to permit of riveting in the event of failure at the welded joints. It was now known that there was no difficulty in producing a reliable welded joint. In fact, the earlier applications of electric welding had been mainly the execution of repairs which could not be completed by any other means; and he was familiar with shipyards in America, Japan, and Great Britain, where the use of electric welding had been rapidly extended after the repair of a pile-driver by the process in each yard.

Digitized by Google

Major Caldwell. He did not agree with the Author's statement (p. 158) as to the extent to which electric welding had been used in the fabrication of structures of considerable size outside of Australia. During the last 9 years he had been actively engaged in promoting the use of welding in Britain, and for the same purpose he had made several visits to the United States and the principal European countries. He appended a list[1] of electrically-welded buildings, miscellaneous structures, and seacraft, which formed a historical record of the development of the electric welding process.

Mr. Cripps. Mr. F. S. CRIPPS congratulated the Author on his originality, perseverance, and courage in applying the electric welding process on such a large scale. If the Author's contentions were correct, namely, that neither strength, durability, reliability, nor economy was impaired, but the reverse, then it would seem that the sooner welded structures became more general the better. This remark

[1] ELECTRICALLY WELDED BUILDINGS AND MISCELLANEOUS STRUCTURES.

Belgium.

(*a*) Masts and towers for high-tension lines.
  (1) Between Malines and Louvain*: 72 feet long, 3 feet 4 inches square section at base.
  (2) Another typical size: 160 feet long, 9 feet square section at base. These masts are 10 per cent. lighter than riveted structures, and cost 40 per cent. less to manufacture. About 3,000 have been made to date.

(*b*) Signal standards for railways.

(*c*) Factory at Haren (skeleton steel structure): 350 feet long, 120 feet wide, 40 feet high. Steel material amounted to 3 lbs. per square foot of floor-area. Saving was more than 50 per cent. compared with the cost of a similar riveted structure.

United States of America.

(*a*) Workshop roof at Brooklyn: roof trusses, 40 feet span.

(*b*) Mill type building at Eola, Illinois: 60 feet span, constructed of scrap structural steel.

(*c*) Roof sign and steel sheds at Schenectady.

Great Britain.†

(*a*) Stable buildings for Horse Show at Olympia, London: Area, 9,000 square feet; roof trusses, 14 feet span. Welded complete by two welders and four helpers in 8 days after receipt of order.

(*b*) Railway sheds at Slough: Welded girders, 50 feet span.

(*c*) Factory buildings.
  (1) Skeleton steel structure at Tottenham, London: Area, 14,000 square feet, 200 feet long, 70 feet 3 inches wide; main trusses, 40 feet

* The construction of these masts was described by Major Caldwell in the Minutes of Proceedings Inst. C.E., vol. ccxiii (1922), p. 341.

† See also *Engineering*, vol. 111 (1921), p. 55.

Digitized by Google

would apply not only to gasholders, purifiers, and other gasworks plant, but also to bridges, roofs, and numerous other structures. If, for example, very large, above-ground, gasholder-tanks, up to 300 feet in diameter, by 45 to 50 feet deep, could be constructed with 100-per-cent. joints, by electric welding, a wide field became open to the process at once, since the cost of large tanks with riveted joints approaching the strength of the solid plates was very high. But objections had to be faced. All the Author's introductory remarks showed the great importance of having trained men in the various departments concerned with the welding process, without which the risk would be too great to venture. Apart from the inexperience of workmen, coupled with greater dependence on them, there was the much greater difficulty and cost when a welded structure had to be dismantled for re-erection elsewhere, particularly large

Mr. Cripps.

---

3 inches; wing trusses, 15 feet span. Erected in 9 weeks from delivery of steel on site, where all welding was done.

(2) Skeleton steel structure at Stoke-on-Trent, with 20-ton overhead crane: Area, 13,000 square feet; main trusses, 50 feet span; stanchions and main girders of box form, built up of stock sections.

(3) Premises with sawtooth roof at Brixton, London: Area, 22,000 square feet.

ELECTRICALLY WELDED SEACRAFT.

Sweden.

Tug: 52½ feet long, 13½ feet beam.

Germany.

River launch: 46 feet long.

Japan.

(*a*) Dry dock: 460 feet long. Practically all joints welded.

(*b*) Floating crane pontoon: 65 feet long, 35 feet beam.

United States of America.

(*a*) Tug: 42 feet long, 11 feet beam. Welded hull plating.

(*b*) Motor boat: 58 feet long.

(*c*) Oil-barge: 76 feet long, 21 feet beam, 11 feet deep.

(*d*) Battle towing target: 172 feet long.

France.

(*a*) Barge: 65 feet long, 13 feet beam. Welded by women.

(*b*) Lighter: 150 feet long, 34 feet beam, 15 feet deep; 1,400 tons.

Great Britain.‡

(*a*) Barge for cross-channel service: 125 feet long, 16 feet beam, 7 feet 9 inches deep. Cost of erection was 23 per cent. less than for riveted barges assembled at the same yard.

(*b*) Motor coaster: 150 feet long; 500 tons.

All the above have successfully withstood sea service, and, so far as is known, they are still in use.—J.C.

‡ Trans. Inst. of Engineers and Shipbuilders in Scotland, vol. lxi (1918), p. 206; and Proceedings Inst. Mech. E., 1922, pt. 1, p. 239.

Digitized by Google

Mr. Cripps. structures such as gasholders. It was common practice to dispose of the plant which was outgrown at one gasworks, for re-erection at another and smaller works. Riveted and bolted joints were easily parted when required, without either damage to the gasholder, or disturbance of size, and all went together again with the minimum of trouble. Could this be said of a completely welded structure? The collapse of the Melbourne gasholder in 1920 had been attributed by the Board of Inquiry to temperature-changes causing the middle-lift cup to break. But the Author scarcely seemed to support that view, as he made no reference to the damaged cup, but mentioned instead the ripping of the corroded crown-sheeting. The latter would appear to be the more likely cause of the accident. It was difficult to see how the temperature could affect the cups, as they contained water and were always more or less pliable and quite free to expand and contract under stress to a greater extent than temperature-changes would demand. The details of construction furnished were scarcely sufficient to enable any certain conclusion to be formed, but it was important to note that 'the thin crown sheeting was ripped off close to the strong plates." The thin sheeting should never be connected direct to the strong plates forming the curb, but the thickness of each ring should be gradually increased as the angle of the top curb or compression ring was approached, $\frac{1}{8}$-inch sheets being riveted to nothing exceeding $\frac{3}{16}$ inch, $\frac{3}{16}$ inch to $\frac{5}{16}$ inch or $\frac{3}{8}$ inch, and so on. It should be pliable like a whip. Not only did joining a thin sheet to a thick plate make it impossible to have a properly proportioned and gas-tight joint, but the thin one might bend up and down on the unyielding thick one, and so weaken the sheet at the lap, as the Author pointed out; for, whenever the several lifts of a gasholder were landed, the rise of the crown was reduced; and on the other hand, when the holder rose and each lift cupped and picked up weight, the crown-sheets were lifted or ballooned out more and more by expansion under stress.[1] At the same time the top curb itself expanded or contracted in diameter. Such movement, unless the crown was properly proportioned, might have caused the local bending on the corroded laps referred to. As new rest-blocks had been fixed in the tank during the reconstruction, could it be that originally there were only twenty-two blocks in all, that was, one block to a bay? If so, when the holder ran down due to the rapid

[1] F. S. Cripps, "An Investigation into the Strains upon the Top Curb of a Gasholder." Trans. Gas Institute, 1882, p. 234, and "Gasholder Crowns," *Ibid.*, 1884, p. 74 (both reprinted in "The Guide Framing of Gasholders and Strains in Structures connected with Gas Works," London, 1889). Also Minutes of Proceedings Inst. C.E., vol. cxlvi (1901), p. 93.

Digitized by Google

escape of gas, the cup would be brought suddenly to rest on the widely-separated rest-blocks and so might have caused the "breakage." There should never be less than two rest-blocks per bay, even for the smallest holders, otherwise there was a tendency for the cup to sag and twist over between the blocks when the holder was landed. The method of resheeting, or rather duplicating the sheeting on, the crown of an existing holder without disturbing the original sheeting, or stopping the use of the holder, was ingenious and well worthy of attention. Unless the welding process were adopted as described, it would be necessary to throw the holder out of use: therefore electric welding in such cases would appear to be highly advantageous. The Author did not mention how the irregular levels caused by the riveted lap joints had been avoided when bedding and welding the outer flat ring to the crown. The laps and rivets of the old crown plates would appear to offer some obstruction. Of necessity the flat ring must have a gas-tight joint all round, or gas would escape from the space between the two layers of crown sheeting. The lower layer—the old crown sheeting—could not be depended on for gas-tightness. Again, unless gas under pressure was admitted between the two layers of crown sheeting, the new layer would be liable to sag between the bars to which it was welded and cause water to lodge in the hollows and rust the sheets. The crown sheeting was, perhaps, the least durable part of a gasholder, so that it was well to have this method of treating it to fall back on in case of necessity. The additional weight due to the double skin was a manifest advantage, because the inner lifts of gasholders were more often than not too light to give sufficient pressure for distributing the gas. The strengthening of crown sheeting by simply laying a loose net or cobweb of steel bars on the top, secured around the outer circle only, did not appear to have so much to commend it. In this country water would lodge and rust would set in on the sheets and under the network of rings and radial bars, where it would be impossible to paint. The vertical stays in the inner lift of a gasholder required to be strong enough to carry the weight of the top curb, and sometimes the weight of the crown and its trussing in addition, when the holder was at rest. Further, they should be rigidly gusseted to the top curb to avoid anything in the nature of a hinged joint. In large holders the bottom ends of the vertical stays should be made use of for stiffening the cup, the cup roller carriages being so constructed as to form a bracket backing against the stays just under the cup. In the normal fully-guided holder, the channel guides in the next or second lift, when at rest in the tank, should

Mr. Cripps.

Digitized by Google

Mr. Cripps. be stiff enough to resist any tendency of the inner lift to tilt before it cupped. After the inner lift cupped they had little to do. When landed, the side sheeting with the stiff rings top and bottom was almost sufficient to carry itself, provided there were enough rest-blocks in the tank. Hence the guides in the remaining lifts had very little to do beyond keeping the several lifts concentric: they had practically no weight to support. The stress due to hanging weight when the holder was up was negligible, since the side sheeting alone was much stronger than was necessary simply to carry the load. All the guides should be rigidly attached top and bottom, and the cup roller carriages utilized for supporting and stiffening the cups and bottom curb, as described for the vertical stays of the inner lift. Of course, these remarks referred to gas-holders having guide-framing to the full height and not depending on the bell to resist overturning. Where the framing was of less height, or was absent altogether, the vertical guides needed to be stronger, to resist the extra stresses induced by the overturning forces and the tendency to distortion.

The most novel feature of the Fitzroy gasholder (Figs. 4, Plate 3), was the shape of the standards, which were broad at the base and tapered for about one-third of their height, the remaining two-thirds being very narrow and parallel. At one time, it was the practice to depend solely on the guide-framing for resisting the overturning force of the wind, but more recently, chiefly from motives of economy, the gasholder bell itself had been called upon to furnish more resistance to this force. In gasholders where the external guide-framing was abolished altogether, as in the spirally-guided holder, the floating bell alone resisted all the stress as a cantilever. And in gasholders having one or two flying lifts, the guide-framing being shortened accordingly, the bell was called upon to offer greater resistence to overturning than when guided to its full height. In the Fitzroy gasholder the bell united with the guide-framing in resisting the overturning; for, although the lower portion of the guide-framing might be sufficient to act alone, the floating vessel might be called upon to act in concert with the guide-framing in the upper part, to resist the maximum wind-pressure. The tops of the standards were very sturdily braced by wind ties round the circumference. That was essential with such light guide-framing, otherwise it was like an empty canister without the lid, which was easily distorted at the top, whereas with the lid on, it required considerable force to distort it. The wind-ties took the place of the lid and stiffened the guide-framing where it was otherwise most pliable. The gas-pressure in the floating holder lent material assistance in

Digitized by Google

preserving its cylindrical form, and it was obvious that, but for that internal pressure, no gasholder without external guide-framing would be safe against wind-pressure, unless of extraordinary weight. The holder might be looked upon broadly as a vertical cylindrical cantilever subject to uniformly-distributed internal pressure and one-sided external pressure. The design of gasholder shown in Figs. 5, Plate 3, was exceedingly light for the strength, but there was a serious objection to the tubular form of structure, which should not be overlooked, namely, that it was impossible to paint or obtain access in any way to the interior of the tubes, which were only about ¼ inch thick and small in diameter. If they corroded or rusted away internally, it could not be observed. It had always been his practice to design the framework for gasholders so that every part was accessible for painting, and, moreover, there should be no lodgments for water or water-traps. For that reason flanges constructed with angles embracing lattice bars should be avoided, as they were so liable to rust between the angles. Wherever possible, in small holders, simple tee-section flanges for girders, struts, and standards were preferable, with the lattice bars on alternate sides. For large holders the table of the tee could be stiffened and strengthened where necessary by the addition of a wide table plate. It was sometimes the practice to fill the space between angles with cement or iron packing. Both were expensive, and the former was very liable to crack out. It was therefore more desirable, unless a solid web was adopted, to avoid the use of double angles for exposed work. There were many different forms of standard, such as the plain joist, the web-plate girder, the double channel, and others, all of which could be constructed so as to avoid water-traps, and to have every part accessible for painting. From Figs. 5 it would appear that only twelve tank-guides were adopted in this design. If so, that was barely sufficient. It was usual to place one opposite each standard and one intermediately, the bottom curb needing to be well supported, as it was more liable to distortion than either the hydraulic cups or the top curb. It would be interesting to know how the steel-plate extension for increasing the depth of the tank had been united to the old brick tank so as to make a sound joint; also whether the standards were bolted down or quite free at the base. In all the three gasholders illustrated, the roller carriages were shown to tower higher above the respective lifts than necessary, which meant extra stress on the grips and carriages, as well as expense. That could be avoided by placing the grip carriage of the outer lift on the side instead of the top of the grip. All other carriages then nestled down snugly. That necessitated the tank-

Mr. Cripps.

Digitized by Google

Mr. Cripps. guides being fixed flush with the standard guides, so as to form a continuous roller-path from top to bottom; in fact, they should never be otherwise. The Paper was of a very interesting and suggestive character throughout, and deserved to be closely studied. If, after the lapse of, say, 20 years, an account could be given of the manner in which the welded structures had stood the test of time, and behaved themselves generally during that period, it would add very much to the valuable information which the Author had communicated.

Mr. Keable. Mr. E. F. KEABLE drew attention to the subject of the internal corrosion of gasholders, which had been given by the Board of Inquiry as one of the causes of collapse of the South Melbourne holder. As the subject of oil-filming of gasholder water-surfaces was being investigated in New South Wales, where unquestionably rapid corrision was due to the evaporation of water contained in the holder, he thought it might be of interest to state that he had obtained very successful results by the adoption of oil-filming, particulars of which had been published.[1]

Associate-Professor Kernot. Associate-Professor W. N. KERNOT congratulated the Author on the enterprising manner in which he had led the way in applying the metallic-arc system of electric welding to new designs and to special types of work. Starting with very few reliable data, he had steadily overcome difficulty after difficulty in a very successful manner, and he had never lost his belief in the ultimate success of this method of fabrication. Throughout, numerous test-pieces had been made and tested, to ensure that the theoretical strengths were actually obtained in practice; and the attainment of an actual 100-per-cent. joint had been always kept in view. When the light construction of a gasholder was considered and the small clearances between the different lifts were taken into account, it was a source of wonder how the structure retained its form accurately. If any considerable distortion occurred, due to the heat generated in welding, a misfit would take place and the structure would be useless. The actual result obtained in the cases of the gasholders mentioned by the Author showed that no such difficulty occurred. It would be advantageous if information were available with regard to the deformation due to the heating of the plates while they were being welded. It has been difficult to reduce what took place to a definite system, and if the accumulated experience from different parts of the world could be gathered together, some fundamental theory might be developed for general guidance. In the meantime

[1] *Gas Journal*, vol. clxxii (1925), p. 846, and supplement, 22 July, 1925, p. 31.

Digitized by Google

individual experience must be the only guide. The following data furnished by the testing of a bar made entirely of electrode metal, as used by the Metropolitan Gas Company and tested at Melbourne University, might be useful for comparison :— Associate Professor Kernot.

Elastic Limit	53,000 lbs. per square inch.
Ultimate Strength	65,400 lbs. „ „
Elongation	13·3 per cent.
Reduction in Area	16·8 „ „

The Author referred to the success of the welding process in bridge-construction, and experience in Victoria had shown that the design and construction of welded roof-trusses could be undertaken with satisfactory results. The salient features of this type of construction were the elimination of gusset-plates and the adoption of sections which lent themselves readily to welding. In small trusses many joints only required one rivet, and he had met with cases in which this single rivet had been damaged during manufacture, with serious results. Welded trusses were very suitable for public halls and similar places where they could be used in the open, as they were less obtrusive than the riveted ones, to which the gusset-plates and the correspondingly wide members gave a heavy and often unsightly appearance. Applications to repair work without interruption of supplies, as in the case of the Fitzroy holder, had been undertaken by, among others, the Victorian Railways, and also by the Commonwealth Railways. Such repairs were required to reduce the stresses in bridges which had been introduced by the increase in the wheel-loads of the locomotives. In the first case the flanges of girders had been strengthened and the rivets connecting the angles to the web had been reinforced by welding, without interruption to the traffic. In the second case similar reinforcement had been made between the angles and the web plates, the floor-system also being reinforced. Many other similar cases of repair were on record. The use of a continuous welded joint overcame a trouble which had occurred in several structures in which riveted joints had failed by corrosion between the plates, with the result that the plates had been forced apart or the rivets badly strained. By careful design many corners and crannies that collected water and became seats of corrosion might be done away with, and the life of girder work exposed to the weather increased considerably. The effect of electrolysis on welded joints was an important matter, to which considerable attention had been given in Melbourne. So far experience was incomplete, but no cause for alarm was anticipated in that direction. In riveted steel pipes the rivets usually showed

Digitized by Google

Associate-Professor Kernot.

signs of distress first, and pipes were often found in which the rivet-heads had almost disappeared. The Author's Company was fortunate in having a trained band of welders whose capacity they knew. The difficulty that others, not so well situated, would have when work was required was that, in spite of the facilities offered for training, sufficient good men were not available at present. At Melbourne University a course of lectures was being given on electric welding, and at the Working Men's College (the Melbourne Technical School) and at Footscray Technical School (Melbourne) special classes were being conducted to train welders. In this way both the designer and the artificer could now receive proper training in the subject.

Mr Moore.

Mr. MALCOLM MOORE remarked that the application of electric welding to the fabrication of structural steel, as developed by the Author and his staff, was attracting the attention of structural engineers in many parts of the world. American engineers, particularly, had been interested in this development of electric welding in Australia, and also in an Australian invention, namely, the Cutler-Marsden automatic welding-machine, which was specially adapted for steel-pipe manufacture and seam-welding generally. Structural engineers had become so used to thinking in terms of riveted joints, and so much tabulated information and tested data were available which made the design of such joints easy and safe, that such a radical change in structural practice as had been adopted by the Author's Company would take time to be appreciated and understood by engineers. A large vertical gas retort-house or a large gasholder was classed amongst the largest steel structures in any city. The fact that such structures had been built practically without a bolt or a rivet, as had been done in Melbourne, was evidence that this welding process was not in any way an experimental undertaking. Mr. Moore's firm had had occasion to take over electric welders and machines from the Author's Company during the execution of certain contracts undertaken for that Company. He had also represented the New South Wales Government Dockyard, where the Cutler-Marsden machines had been developed in connection with some large steel pipes and structural undertakings, so that he was familiar with these electric-welding developments in Australia. The Author's practice was to adopt covered electrodes, working as he did on material ranging from the thin sheeting of gasholders to steel framing of the heaviest type. Also, he operated largely in the field, under conditions of exposure to weather and where rusty materials were unavoidable. In such circumstances it must be possible to regulate the

Digitized by Google

volume of current closely to suit the thickness of material and other welding conditions. A heavy flow of current would burn the lighter material and cause excessive distortion. Under such conditions the covering on the electrode was undoubtedly valuable in slagging off rust and field impurities, in protecting the weld from oxidation, and in assisting to get a satisfactory bond between two runs when a large joint was built up by several layers of welding, etc. The Cutler-Marsden machine, on the other hand, was used on comparatively heavy material, usually under shop conditions, and employed a heavy current. A weld made by that machine was formed more by fusing the parent metal in the two plates which were being welded and running this molten metal together under the kneading action of the electrode itself, than by the fusing of the electrode into the joint in the manner of a soldered joint. The electrode acted most simply as an electrode, rather than as a supply of welding material, and ordinary bare mild-steel wire fed to the machine from coils as they were received from the wire-drawing works formed an excellent joint. Mr. Moore.

As pointed out by the Author, it was essential that engineers undertaking the use of this new process extensively should exercise great care in selecting and training suitable men. A riveted joint could be inspected and judged as to its strength at any time. A welded joint might look quite satisfactory on the outside, yet might develop a poor result on being tested. When a welded joint was painted, it was impossible to judge its quality by inspection. Another matter which was of vital importance in adopting electric welding for new construction work was that the joints and general design should be laid out to suit electric welding. Where this was done, the simplicity and economy of the process was certainly remarkable in many types of structural work. Gussets were practically eliminated. Small sections could be adopted, and their full strength developed, there being no weakening for rivet-holes. Joints to columns could in many instances be considered fixed, whereas in structural practice they would be considered hinged. In difficult joints and compact built-up structures where it was impossible to get rivets in, electric welding could be applied without any such difficulty. For structures like tramway-car bogies, where there was always great difficulty in developing the full strength of the sections used and in getting the required number of rivets in, electric welding was particularly advantageous. The Author stated (p. 160) that his Company had now as full a knowledge of the requirements of a welded joint as of those of a riveted connection. Mr. Moore has seen something of the thoroughness with which this matter had been

Digitized by Google

Mr. Moore. undertaken by the Author's staff. Every engineer was familiar with the manner in which common joints were tabulated in structural steel hand-books, showing the required number and the most suitable arrangements of rivets. The Author had done the same in connection with his electric-welding practice, and further, he had had actual tests to destruction carried out on most of his standard types of electrically-welded joints. It would be too much to suggest that the exhaustive information used by his design staff should be made available through The Institution, but the more commonly used of his data would be of very great value to engineers in their handling of electric-welding problems. If the Author would set out the value per linear inch, in tension, shear, and compression, of the different types of joints, with different quantities of electrode per linear inch, and would illustrate a few of the more common joints, such as that connecting an angle cross brace to a column, or a joist acting as a beam to a joist acting as a column, and a few more similar joints, giving examples of how the strength calculations were handled by his design staff, a valuable supplement would be made to his interesting and useful Paper, and he would give engineers some confidence in using electric welding in their structural problems.

Mr. Ritchie. MR. E. G. RITCHIE observed that he had inspected the electric-welding work carried out under the Author's control, and desired to take the opportunity of acknowledging the value of the pioneering work performed, which had given much inspiration and encouragement to others engaged in electric welding for structural work in Australia. When the question of the application of such a method for fabricating large steel water-mains was under consideration for the Melbourne water-supply system, he had considerable doubts as to the probable effect of corrosion on the welded joints. By the Author's courtesy he had been enabled to inspect specimens of welded steel which had, during the manufacture of gas, been subjected to corrosive action far more severe than was considered likely to take place in the water-mains referred to. He had been particularly impressed with one specimen consisting of the worn-out remains of a retort-stopper. This had been exposed to sulphur fumes, and the metal had moreover been subjected to frequent applications of water whilst at a high temperature. Corrosion had been very severe, the life of the stopper having been only about 6 months. Notwithstanding this fact, whereas the steel plates had been entirely worn in parts, the weld bore evidence of resistance to corrosion markedly superior to that of the plate. From such evidence, and from the corrosion tests carried out by the Author,

Digitized by Google

much reassuring testimony was available as to the resistance to corrosion of electrically-welded joints, and Mr. Ritchie felt that, provided careful attention were given to the coating of the joints, there should be no doubt as to their durability. The Melbourne water being very soft and unusually free from chemical impurities, the principal danger appeared to be from external corrosion, and, for this reason, the additional precaution had been taken of laying the pipes so that, wherever possible, the welds were placed as far as practicable from the invert, at which part of the pipe external corrosive agencies were always the most active. As the Author rightly pointed out, electric welding, properly applied to designing, was capable of effecting great economies. That was particularly the case in a young country like Australia, remote from the sources of steel-plate production. Steel plates in the larger sizes, such as were used in the works described in the Paper and in the manufacture of large water-mains, were usually imported from either England or America, and the desire to save in the weight of raw materials was in consequence greatly stimulated. For many years the large steel mains of the Melbourne water-supply system had all been fabricated by riveting, but in 1912 this was superseded entirely by the use of the lock-bar joint, which, like the electrically-welded joint, had a strength fully equal to that of the plate. Hammer and roll welding of longitudinal joints of large pipes, as practised in America, in England, and on the Continent, had not been employed in Australia, but the use of electric welding was being rapidly extended. The first electrically-welded steel pipes were, under Mr. Ritchie's directions, used in the Melbourne water-supply system in 1924. The total mileage of electrically-welded steel pipes put into use in the system up to the present date (May, 1926), was shown in the Table on p. 202. In addition, contracts had been let for about 4 miles of 30-inch diameter, and 4 miles of 46-inch diameter electrically-welded steel pipes. Mr. Ritchie

He had also found the use of electric welding for field work on steel water-mains extremely valuable and economical. The plant employed consisted of Fordson tractors, each of which carried its own electric generator, belt-driven by the tractor engine, the whole being a compact unit capable of travelling under its own power along steep and rough pipe-tracks. Those units had proved reliable and satisfactory in service, and had been used for fixing clips, bands, etc., to the steel pipes, thus replacing the use of rivets and bolts. They had been valuable also in effecting repairs to older steel water-mains, such as patching plates weakened by external corrosion, some of the repairs having been effected while the mains were

Digitized by Google

Mr. Ritchie. carrying water under pressure. The Author referred to the application of electric welding in a design for a 24-inch welded steel main of 90 feet span over Gardiner's creek, and it might be of interest to give particulars of a somewhat similar structure recently completed, namely, a 54-inch diameter steel main used on the main

ELECTRICALLY-WELDED MILD-STEEL PIPES.

Diameter.	Date of Contract.	Thickness of Plate.	Lap or Butt Welded.	Total Length of Pipes in Contract.	Remarks.
Inches.		Inch.		Linear Feet.	
54		$\frac{3}{8}$	Lap	8,700	
54		$\frac{1}{2}$	,,	11,472	
54		$\frac{7}{16}$	,,	4,800	
54	13/12/23	$\frac{5}{16}$	,,	8,400	
54		$\frac{1}{2}$	,,	8,700	
46		$\frac{1}{2}$	,,	6,157	
34		$\frac{1}{2}$	,,	2,633	
46	18/12/23	$\frac{1}{2}$	,,	53,716	
15	3/1/24	$\frac{3}{16}$	Butt	9,100	
24		$\frac{1}{2}$	,,	11,002	
12	24/1/24	$\frac{3}{16}$	,,	42,192	
72	22/5/24	$\frac{1}{2}$	Lap	1,005	
27	2/6/24	$\frac{1}{2}$	,,	67	
30		$\frac{1}{2}$	,,	118	
9	21/11/24	$\frac{3}{16}$	Butt	23,616	
12		$\frac{3}{16}$	,,	7,698	
15	15/1/25	$\frac{3}{16}$	,,	9,438	
18		$\frac{3}{16}$	,,	1,320	
12	3/7/25	$\frac{3}{16}$	,,	9,120	Cement-lined
9	27/8/25	$\frac{3}{16}$	,,	5,130	,, ,,
16	16/12/25	$\frac{1}{8}$ and $\frac{3}{16}$	,,	7,095	,, ,,
16	11/2/26	$\frac{3}{16}$	,,	3,070	,, ,,
46	10/2/26	$\frac{1}{2}$	Lap	20,856	
30	23/3/26	$\frac{1}{2}$	Butt	21,384	
31	16/4/26	$\frac{3}{16}$	,,	5,300	Cement-lined
9	19/5/26	$\frac{1}{8}$ and $\frac{3}{16}$	,,	1,340	,, ,,
		Total Length . . .		283,429	= 53 miles 54½ chains.

NOTE.—Automatic welding-machines were employed for the whole of the above pipes. Bare electrodes were used, except for pipes 9 inches, 12 inches, and 16 inches in diameter made since the 2nd June, 1924; for such pipes covered electrodes were used.

Digitized by Google

O'Shannassy pipe-conduit for the Melbourne water-supply. The pipes used were of ½-inch plates, and were electrically welded throughout, except at the joints of individual pipes, which had flanges welded on them and were bolted together. The span was 40 feet. That pipe carried a pressure of about 270 lbs. per square inch. Reinforcing flange collars were welded on the pipes at intervals to strengthen them against collapse, the pipe-span being unsupported by either girders or brackets. He agreed generally with the Author that the results so far attained afforded promise of a greatly enlarged field of usefulness for electric welding in future, in place of using rivets and bolts. Mr. Ritchie.

The AUTHOR, in reply, expressed his gratification that the discussion and correspondence had elicited many points, the omission of which from the Paper had been due to the limitations of his experience. The Author.

The examples of constructional work mentioned in the Paper had been referred to by the President as light structures. This, however, could hardly be said to be the case, as gasholders required in their construction quite heavy sections and plates. It was true that the greater part of the surface of the holder was covered with light sheeting, but that sheeting, although it constituted the envelope for containing the gas, was supported by framework of considerable strength. He would emphasize the fact that, although much light sheeting had been welded, yet he had built many heavy structures.

Early in his welding experience, he realized the lack of reliable information as to the question of the strength of the weld. In order to modify the design of structures and plant to suit the new jointing methods, considerable investigation and testing had been carried out, and, as had been pointed out by one of the correspondents, a great deal of valuable information on the subject had been collected. It had been conclusively proved that the strength of the weld differed little, if at all, from the tensile strength of the steel; but for the purpose of rational and safe design, standard values had to be evolved, which necessitated consideration of the type of electrode employed, the characteristics of the labour available, and the particular class of work to be carried out. It might be considered an axiom, however, that welded joints in material up to $\frac{1}{16}$ inch in thickness could not well be made of less than 100-per-cent. efficiency; joints in heavier plates or sections should be so designed that that efficiency was attained.

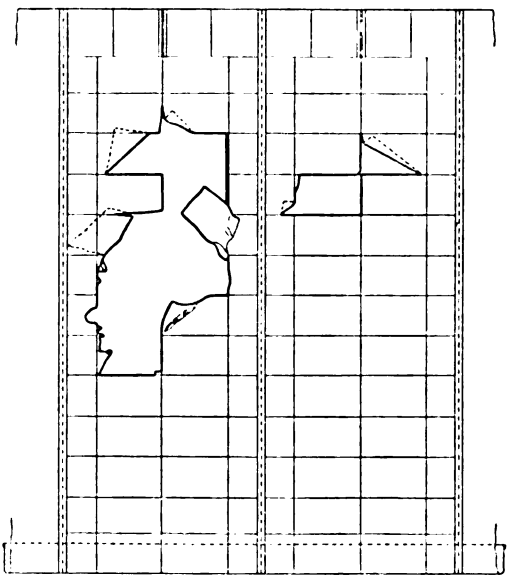
It had been found that the employment of welding instead of riveting tended to stiffen a structure, although riveted joints seemed to give an appearance of great rigidity. It was obvious, however, that a structure composed of a large number of plates and sections

Digitized by Google

The Author. joined by riveting remained an aggregation of units, whereas if it were welded it would constitute a homogeneous whole. In the case of plate-jointing a lapped joint welded on both sides of the lap was invariably stiffer than a corresponding riveted joint. The width of a lap when welding was employed should not be less than that of the lap when riveting was proposed in equivalent circumstances, and the joint should always be welded on both sides of the lap. He preferred never to have recourse to a butt joint when it was possible to employ a lapped joint.

The question of the cost of some types of covered electrodes had been raised in the discussion. The Author was of opinion that the

Fig. 8.



cost of the electrode in a properly-designed welded structure was so small as to be unworthy of serious consideration. It must not be forgotten that it was the employment of the electrode that rendered economy through the use of welding possible, in connection with which some very illuminating examples had been cited by Major Caldwell. With careful design, and with workshops and field erection properly organized to make the fullest use of the advantages of electric welding, it was surprising to see the savings that could be effected. The considerable shop-work necessary for a riveted structure was eliminated in the case of a similar structure for which welding was employed. For example, in the construction of a steel

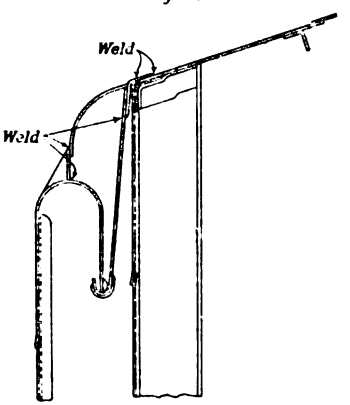
Digitized by Google

tank the operations of marking-off, shearing, planing, and punching or drilling were unnecessary when welding was employed. The heavier plates, of course, had to be rolled to the required curvature, but the cost of setting up machines on the site of erection could easily be covered by the saving arising from the reduction in freight; and, if the work was being carried out in countries subject to a high fiscal tariff, great saving could be effected by importing as much material as possible in the raw state, and performing such fabrication as might be necessary on the site. The Author.

The broad principles of design remained unchanged; it was in the details that the employment of welding made such revolutionary changes.

In the construction of the North Melbourne gasholder which was completed in October, 1926, no sheet smaller than 15 feet by 4 feet

Fig 9.



was used; those sheets were straightened and punched for the tacking-bolts and handled into and out of the shop at a total labour cost of 8*s*. 6*d*. per ton. When it was considered that boiler-maker's wages were 19*s*. 8*d*. per 8 hours, and their assistants' wages 16*s*. 2½*d*., it would be admitted that this cost was extremely reasonable.

He congratulated Mr. Plumstead on his repairs to the Norwich gasholder. He would, however, make it clear that such a method of repair would have been quite impossible in the case of the North Melbourne gasholder on account of the huge rents that had been made in the side sheeting of that structure (*Fig. 8*). The only possible means of repair had been to join the damaged inner lift and the middle lift together (*Fig. 9*) as was done by the Author. The question of the behaviour of iron sheets had been raised, and the

Digitized by Google

The Author. Author was able to state that, in the latest holder built, iron sheets of a well-known brand of remarkable purity had been employed, with altogether satisfactory results as regarded welding. The metal of the sheets corresponded very well with the deposited weld metal, as was shown by microphotographs, where no discernible difference was apparent.

The reconstruction of the North Melbourne gasholder, which had been done since the presentation of the Paper, afforded another example of the advantages of electric welding. The old structure, weighing 525 tons, had been cut out and removed and the new three-lift holder—of a capacity of 3 million cubic feet, and weighing 550 tons—had been erected in exactly 6 months, with an average of forty-five employees on the erecting work, which included necessary repairs to the tank, tank-framing, rest-blocks, etc.

It was true that welding, particularly in its earlier stages, had suffered to some extent from both ignorance of the subject and the fact that inferior workmanship was often evident. The point could not be too often emphasized that the organization of the establishment should be such that the welder should be called on to supply the manual dexterity only.

All his investigations had shown that there was no hardening of the metal adjacent to the weld. An extensive series of physical and metallographical tests had been made at Melbourne University, which showed that the metal adjacent to the weld had not deteriorated but had rather been improved.

Some of the members who had contributed to the correspondence were resident in Melbourne and had, therefore, had opportunities of gaining first-hand knowledge of the Author's methods and work. There was no doubt that the Australian workman could do as well as any other workman, and it had been a pleasure to the Author to note the enthusiasm for the work shown by very many of them with whom he had come in contact.

He entirely agreed with Major Caldwell as to the often difficult conditions in pioneer undertakings, as he knew from experience; and he was glad to know of the large number of buildings and structures that had been fabricated by the use of electric welding, not only in Great Britain and the United States of America, but in Continental countries.

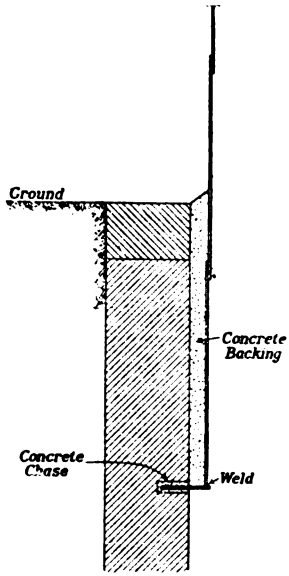
He appreciated the contribution of Mr. Cripps, who was, without doubt, the greatest authority on gasholder design and construction. Mr. Cripps's work on the guide-framing of gasholders and gasholder and tank construction had been utilized by the Author for many years with great advantage. If it was anticipated that a piece of plant, whether a gasholder or any other plant, would require to be removed for

Digitized by Google

erection elsewhere at any time, it would, of course, be preferable to use rivets; but this would apply to small structures only, and not to those of the size described in the Paper. As to stresses due to temperature-changes, it was well to remember that the variation in Melbourne was probably much greater than anything experienced in Europe, a difference of 40°F. in a few hours being not unusual in the summer. The number of rest-blocks was forty-eight, and the Author entirely agreed that blocks close enough to reduce the strain on landed cups were essential. The difficulty of the irregular levels on the crown when new sheeting was superimposed was overcome by welding a fillet to the strong crown curb-plate and welding the new sheeting to the fillet. It was true that there might be corrosion between the

The Author.

Fig. 10.



members of the net or mattress which was employed on several of the crowns of gasholders, but that did not give the Author anxiety in Melbourne. The vertical stays in the inner lifts of the holders described were very strong, and Mr. Cripps's remarks with reference to the design shown in Figs. 4, Plate 3, were appreciated.

The tubular form of construction (Figs. 5) had not been undertaken without careful consideration; there was no risk of corrosion in the interior of the tubes, inasmuch as they were hermetically sealed by means of diaphragms welded in them, which not only effectually prevented access of air or water but also considerably strengthened the tubular columns.

Digitized by Google

The Author. The connection of the steel tank extension was shown in *Fig. 10*; but perhaps a more interesting matter was the ingenious method of erecting the steel-plate extension, which reflected great credit on the erecting staff. The steel-plate extension was 17 feet 6 inches in height overall and projected 6 feet down into the tank, providing an extra depth of 11 feet 6 inches. The extension was composed of four tiers of steel plates, the lowest being $\frac{3}{8}$ inch thick, the next $\frac{5}{16}$ inch, and the two upper tiers $\frac{1}{4}$ inch thick. No fabrication work was done to the plates, which were used just as they came out of stock, with the exception of the $\frac{3}{8}$-inch plates which had to be rolled to curvature. The absence of bolt-holes necessitated a different method of erection, and the usual procedure of setting out work of this nature from rivet centres had to be altered. All horizontal measurements were taken from the right-hand edge of each plate, and all vertical dimensions were taken from the upper edges, allowing any excess of metal to disappear into the laps. As already stated, the Author's practice, wherever possible, was to employ the same distance of lap that would be called for in a similar riveted lap. That condition was observed to lessen the effects of bending, and any excess of metal in a lap was an advantage. The two lower tiers had to be erected and welded up complete on bearers above the tank level, as the diameter of the steel extension, being 3 inches less than that of the existing tank, prevented the welding of the back of the laps in the plates in situ. Lugs, cut out of scrap rolled-steel joists, were welded to the plates, and the lowering-screws were attached to them. After the plates were lowered into position these lugs were cut off. The first tier of plates was held together by means of cramps, over the vertical laps, until the plates in the whole tier had been welded. The erection of the next tier was started by welding an L-shaped lug at the correct height on the inside of the tier below. The end of the plate was dropped into this lug and the plate was levelled in the slings. Further lugs were welded on as required, and steel wedges were driven into them, forcing the plate-edges together, which were then tack-welded, the lugs being knocked off for re-use. Erection proceeded as easily and as rapidly as if bolts had been used. The time spent in welding was not much more than the time required to caulk a similar riveted tank. When the tank was filled with water, there was no sign of any leak. Columns were bolted to the tank-coping and welded by gusset plates to the tank-extension. The roller-carriages, which, by the way, were of a special design admitting of ease of adjustment, were a little higher than was customary, owing to the outer lift carriage being placed purposely on top of the dip instead of on its side. This had many advantages,

Digitized by Google

notably ease of inspection and alteration and the fact that the same size of roller could be used as on the other carriages. The Author.

The question of covering the water in gasholder-tanks with a film of oil had early been considered by the Author, and the holders illustrated in Figs. 3 and 4, Plate 3, were so treated. A serious fire occurred in a timber-yard within a short distance of the holder shown in Figs. 4, which gave the Author considerable anxiety as to its effect on the oil film on the holder sheeting, but happily no damage was done. In Melbourne corrosion was noticeably more severe on the north-westerly area of structures which were exposed to the afternoon sun.

He was indebted to Associate-Professor Kernot who, with Professor Payne, had been of great assistance in testing various joints, both riveted and welded, and in investigating various matters. The effect of electrolysis was very evident in certain districts in Melbourne and its suburbs. He desired to acknowledge the valuable work done in connection with electric welding by Mr. Cutler, and he was familiar with the Cutler-Marsden welding-machines which used as an electrode a mild-steel bare wire. The application of such a machine was limited to straightforward work such as pipe-welding. There was room, however, for a plant mechanically operated as to length of arc but manually controlled as to position. His desire to keep the Paper within reasonable limits had precluded the inclusion of much data and many experiments and experiences which would have proved helpful to engineers interested in welding. Mr. Ritchie had referred to the application of electric welding to the construction of water-mains especially, and had mentioned a particular instance of the absence of corrosion in the welded metal. The Metropolitan Water Board of Melbourne had used welded-steel mains very extensively, and the Author was glad if any pioneer work of his had helped towards this end.

He had been particularly concerned with the question of corrosion of either the welding metal or the metal adjacent to the weld, and that had not been touched upon seriously in the discussion. Experience was continually pointing to the fact that the corrosion of the weld and the metal adjacent thereto was much less severe than in the original metal of the structure, whatever it might be. That was presumably due to the fact that the deposited metal was probably purer than the material to be welded.

Experiments showed that there was little difference between mild steel of good quality and the deposited metal, tensile tests showing a strength of 28-32 tons per square inch.

Other experiments had been carried out in the direction of

Digitized by Google

The Author. welding, or rather brazing, cast-iron pipes. In these experiments, which had been made on gas-mains, alloys of brass had been used and generally satisfactory results had been attained; the joints proved to be tight with an air-pressure of 60 lbs. per square inch, and the strength of the mains was but little impaired.

In conclusion, he was of opinion that the directions in which electrical welding might be used had as yet been only lightly touched upon, and in the future the use of riveting would be reduced and would ultimately disappear.

Digitized by Google

27 April, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D.Eng., President, in the Chair.

It was resolved :—That Messrs. A. H. Case, H. J. Deane, F. M. G. Du-Plat-Taylor, W. Fairley, C. O. Grimshaw, C. Hitchcock, J. M. Kennedy, and S. C. Lewis be appointed to act as Scrutineers, in accordance with the By-laws, of the ballot for the election of the Council for the year 1926–27.

The Council reported that they had recently transferred to the class of

Members.

ARTHUR CHARLES BROWN.
HENRY WILLIAM BLAND COTTERILL.
MAURICE NEWENHAM CRAWFORD.
HARRY CLEMENT RITCHIE.
EDWARD GEORGE WALKER, B.Sc. (Eng.) (*Lond.*).
WILLIAM YATES.

And had admitted as

Students.

HUBERT REYNOLDS BACH.
ROBERT BOOG WATSON BANNERMAN, B.Sc. (*Edin.*).
CYRIL HENRY BRADBURY.
DOUGLAS WATSON BROWN.
JAMES NORMAN MCKAY CAMPBELL, B.Sc. (Eng.) (*Lond.*).
GEORGE LEONARD CASSIDY.
WILLIAM ALEC DYER DAVEY.
IAN CECIL EASTON.
ROBERT FORRESTER.
JOHN FERGUSON FRASER.
GEOFFRY ANNESLEY FERRAR GRINDLE.
JOHN CLINTON KEATING B.Sc. (Eng.) (*Lond.*).
HAROLD GRAHAME KING.
JOHN JOSEPH LIPTROTT, B.Sc. (Eng.) (*Lond.*).
PETER MCNEE, B.Sc. (*Glas.*).
LEO HENRY PAUL MEYER.
JOHN PARKER, B.Sc. (*Durham*).
JOHN VINCENT PATERSON.
MAHADEL PRAMANIK, B.Sc. (*Calcutta*).
NARAINDAS RUPCHAND RAMCHANDANI, B.E. (*Bombay*).
CHARLES EDWARD RUSBRIDGE, B.Sc. (Eng.) (*Lond.*).

The Scrutineers reported that the following candidates had been duly elected as

Members.

WILLIAM JOHN DUNNING.
CECIL LEWIS FORTESCUE, M.A. (*Cantab.*).
CHARLES MURRAY INGLEDEW.
WILLIAM ONYON, M.V.O., *Engr.-Captain*, R.N. (*ret.*).

Associate Members.

WILLIS DIXON, Stud. Inst. C.E.
ROBERT ELLIS.
JOHANNES ADRIANUS VAN HEEL, B.Sc. (Eng.) (*Lond.*).
JOHN CYRIL JONES, B.Sc. (Eng.) (*Lond.*).
DENIS COURTENAY LUCK.
ALEXANDER DAVIS MACKAY, B.Sc. (*Cape Town*).
DONALD HARCUS SCOTT.
JOHN UMBRIA SINCLAIR, B.Sc. (*Edin.*).

Digitized by Google

Associate Members—continued.

WILLIAM ROBERTS GRIGOR TAYLOR. | KENNETH BEALE TURNER, B.A.
JOHN EVERSFIELD TRUZZELL. | (*Cantab.*), Stud. Inst. C.E.

Associate.

ARTHUR JOSEPH MOORE.

The following Paper was presented for discussion, and, on the motion of the President, the thanks of The Institution were accorded to the Author.

(*Paper No. 4595.*)

"The Triple-Expansion Steam-Engine as applied to the Pumping of Water, with special reference to the Plant at Lea Bridge."

By HUGH RALPH LUPTON, M.A., Assoc. M. Inst. C.E.

IN this Paper the Author attempts:—

(1) To give a brief sketch of the general features of the design of a modern triple-expansion steam pumping-plant, taking as typical the set recently installed for the Metropolitan Water Board at Lea Bridge.

(2) To give an account and analysis of the test recently carried out on this plant.

(3) To investigate, in the light of the test, what improvements are likely to be made in this type in the near future.

(4) To compare this plant with other kinds of pumping-machinery for similar duties, as regards cost, economy, and reliability.

The Author feels that an apology would be due for taking up so much time in the description of what has almost become a classic design of machinery, were it not for the fact that of recent years there seems to have been such a striving after something new in waterworks machinery, a striving which has not always led to improvement, but often to the reverse.

THE LEA BRIDGE PLANT.

The Lea Bridge plant, typical of the three-bed type of inverted vertical triple-expansion pumping-engine working ram pumps only, is designed to pump 12 to 14 million gallons per 24 hours against a head of 180 to 200 feet. The engine (Figs. 1, Plate 4) is carried on the pumps, the foundation thus obtained being particularly stable

Digitized by Google

owing to the necessity of having two valve-boxes for each ram-case. There are therefore six valve-boxes, which with the air-vessels above them form six columns on which the six engine girders rest. The whole plant is thus self-contained, and as it is carried on the pump base-plates only, no stresses need be taken by the foundations. Longitudinal mild-steel joists are provided, into which the ends of the cast-iron engine girders fit, but these do not normally take appreciable weight, their sole object being to allow of the removal of a valve-box, should this ever be desired, without disturbing the engine-bed above it. Each ram-case is also tied by two stays to the corresponding engine-bed, so that the water load is directly taken and need not come on the ram-case branches or foundations. Reheater receivers are provided between the cylinders, which latter are steam-jacketed. The high-pressure reheater is heated by the steam on its way to the h.-p. cylinder, and the intermediate-pressure reheater and the jackets by steam tapped from the steam-pipe just before entering the h.-p. cylinder. For intermediate-pressure and low-pressure the heating steam is throttled. Two flywheels are placed between the cylinders, and the crank-shaft is of the "flexible" type, the joint being at the i.-p. crank-pin. The valves are of the Corliss type, worked by Craig valve-gear from a layshaft through eccentrics and cams at cylinder level. This gear, naturally, absorbs considerably less power than do gears which are worked by eccentrics on the main crank-shaft. The speed can be varied by adjusting the cut-off while the engine is running, the sole function of the governor being to trip the steam-valve and spoil the vacuum should the speed exceed any assigned limit. Forced-feed lubrication, at two pressures, is provided for all parts under steam-pressure, and continuous sight-feed lubrication to all bearings and slides.

The pumps are of the outside-packed ram type, the ram-case being furnished with thick sleeves so that it would be possible to replace the present rams with larger ones should more water be required at some future time. The suction and delivery valves are multiple, of hard rubber, working on gun-metal grids, and are, as already stated, accommodated in six boxes. The valve-plates are separate castings and are arranged so that there are no internal joints between them and the boxes. The valve-seats are held down on to hard rubber joint-rings by studs and tripod clamps.

The surface condenser is placed on the pump delivery. There are twin air-pumps, driven from the l.-p. pump crosshead. The pumps draw from a well outside the engine-house, which is fed by gravity from an adjacent battery of slow sand filter-beds.

The delivery water is pumped into a 36-inch cast-iron rising main

Digitized by Google

terminating in a balancing reservoir, but the bulk of the water is passed into the distributing system direct.

The leading dimensions and particulars of the plant are given in Table I.

TABLE I.

Engine and Pumps.	Makers.—Messrs. Hathorn, Davey & Co., Ltd., Leeds.	
	Quantity pumped per 24 hours . . . million gallons	14
	Head . . . . . feet	200
	Pump horse-power	590
	Engine cylinders . . . . . diameter, inches	24, 44, and 66.
	Rams . . . . . ,, ,,	28
	Stroke, engine and pumps . . . . . feet	4
	Normal speed . . . . . r.p.m.	30·0
	Maximum speed . . . . . r.p.m.	30·5
	Normal steam pressure . . lbs. per square inch gauge	190–195
	Normal superheat. . . . . °F	75–100
Steam-Raising Plant.		
Lancashire Boilers and Superheaters.	Makers.—Messrs. J. Thompson, Ltd., Wolverhampton.	
	No. of boilers	4
	No. of boilers working	2
	Diameter	7 ft. 6 ins.
	Length inside of end plates . . . . . feet	26
	Capacity of each boiler . . lbs. evaporation per hour	3,000-4,000
Economizer.	Makers.—Messrs. E. Green & Co., Ltd., Wakefield.	
	Surface area . . . . . square feet	1,600

TEST.

The guaranteed duty of the engine was that it should pump 12 to 14 million gallons of water per 24 hours against 180 to 200 feet head of water, the steam-pressure to be 190 to 195 lbs. per square inch (gauge), with a superheat of 75° to 100° F., and the steam-consumption not to exceed 10·9 lbs. per pump horse-power-hour by displacement, an allowance of $2\frac{1}{2}$ per cent. being made to cover errors in measurements. The test[1] was conducted on the 28th July, 1925, by the Board's engineering staff, in conjunction with the contractors. The principal readings are given in Table II.

TABLE II.—SUMMARY OF ENGINE TEST DATA.

Duration of test . . . . . hours	9
Average pressure by gauge of steam at engine stop-valve lbs. per square inch	181
Average vacuum (exhaust steam just entering condenser) inches of mercury	27·7

[1] A complete record of the test can be seen in the Institution Library.

Digitized by Google

Average barometric pressure . . inches of mercury	29·90	
Average temperature of steam at entry to h.-p. reheater °F.	504	
Superheat . . . . . °F.	124	
Average revolutions per minute	28·76	Whence pump horse-power (by displacement) = 530
Average delivery gauge reading—feet above engine-house floor	171·4	
Average suction gauge reading—feet below engine-house floor	18·6	
Indicated pump horse-power—		
(a) Pump under h.-p. cylinder.	179	Total 532
(b) Pump under i.-p. cylinder	171	
(c) Pump under l.-p. cylinder	182	
Indicated engine horse-power—		
(a) High-pressure cylinder	205	Total 566
(b) Intermediate-pressure cylinder	177	
(c) Low-pressure cylinder	184	
Water collected from air-pump discharge per hour. lbs.	4,967	Total consumption per hour 5,618 lbs.
Water collected from jacket and reheater receiver-drains per hour . . . . . lbs.	651	
Hence the following results :—		
Steam-consumption per indicated horse-power-hour of engine . . . . . .lbs.	9·92	
Steam-consumption per pump horse-power-hour, water delivered (slip neglected) . . . . . .lbs.	10·60	
Mechanical efficiency of pumping-engine complete = $\frac{\text{Pump horse-power} \times 100}{\text{Indicated horse-power}}$ . . per cent.	93·6	

Two of the steam boilers were tested at the same time as the pumping-engine, and the results of this test are given in Table III. Complete data appear in Appendix A.

TABLE III.—SUMMARY OF BOILER TEST DATA.

Fuel	Nixon's Navigation, Welsh, large steam coal.
Calorific value . . . . . B.Th.U. per lb.	15,006
Weight of coal fired per hour . . . . . lbs.	688
Weight of feed-water per hour . . . . . „	6,630
Temperature of feed-water entering economizers . °F.	124
Temperature of feed-water entering boilers . . . °F.	197
Hence the following results :—	
Weight of coal used per pump horse-power-hour . . lbs.	1·30
Water actually evaporated per pound of coal . . „	9·65
Equivalent evaporation from and at 212° F. per pound of coal (excluding economizers) . . . . .lbs.	11·1
Equivalent evaporation from and at 212° F. per pound of coal (including economizers) . . . . .lbs.	11·7

Digitized by Google

Thermal efficiency of boilers and superheaters (excluding economizers) . . . . . per cent.	71·5
Thermal efficiency of boilers, superheaters and economizers . . . . . per cent.	75·4
Overall thermal efficiency, coal to water, of boilers, superheaters, economizers, steam pipes and pumping-engine complete. . . . . per cent.	13·0
Efficiency ratio : indicated horse-power as compared with perfect engine working on Rankine cycle . per cent.	72·0
Efficiency ratio : pump horse-power as compared with horse-power of perfect engine. . . . . per cent.	67·0

Table II shows that the actual steam-consumption of the pumping-engine under test was 10·60 lbs. per pump horse-power-hour, as against the figure of 10·9 lbs. in the guarantee. The improvement over the guaranteed steam-consumption was thus 2·75 per cent., without taking advantage of the 2½-per-cent. allowance for errors.

The air-pump discharge and the discharges from the jacket-drains and reheater receiver-drains were measured separately, and they are corrected for temperature calibration of tanks. Readings of steam-pressure and temperature, vacuum, delivery and suction head, counter, etc., were taken at 10-minute intervals, the time for taking these being given by an electric alarm clock. The depth of water-level in the suction well below engine-house floor-level was registered by a float recorder in the engine-room, and the delivery head was read from a tested pressure-gauge fixed on the delivery side of the pump.

It will be noticed that there is a difference between the quantity of water fed to the boilers, as measured by a 2-inch Kennedy meter, and that obtained from the air-pump and drain discharges. This was due to the consumption of the boiler feed-pumps and other auxiliaries. The figure 1·3 lb. of coal per pump horse-power-hour, however, takes account of all the steam raised, not only of that passing through the engine.

The actual working head on the pump is approximately 160 feet of water, and in order to obtain heads of 180 to 200 feet, specified in the guarantee, the delivery main was throttled by partially closing a main sluice-valve outside the engine-house.

Besides the official test recorded above, a preliminary 4-hour test was run on the 26th June, 1925, with the l.-p. jacket shut off, and a short test was also carried out on the 10th February, 1926, the object of which was to isolate as far as possible the consumptions of the different jackets and reheaters. It was very difficult to measure accurately the joint discharge from the i.-p. jacket and i.-p. reheater tube drains, owing to the comparatively large amount

Digitized by Google

of water and vapour which was lost. The results actually used were therefore obtained by subtracting from the total jacket and reheater consumption obtained on the official test the consumptions of the h.-p. jacket and reheater and l.-p. jacket obtained on the test of the 10th February, 1926.

Analysis of Test.

(A) Conversion of Heat-Drop Available into Indicated Horse-Power.

The ratio of the indicated horse-power of the engine per pound of steam used to the power of a perfect engine per pound of steam used between the same limiting conditions is 72 per cent. The Author has attempted to trace, as far as possible, the channels through which the 28 per cent. loss escapes. Figs. 2, Plate 4, show actual indicator-diagrams taken during the official test, and Fig. 3, Plate 4, represents at AFHE′ the ideal indicator-card of a single-cylinder perfect engine working between the same limits. All the steam fed to this engine is, of course, expanded in its cylinder, none being used for jacketing. Throughout the following calculations of losses the percentages quoted are reckoned on this area as 100. Inside this perfect diagram are shown, slightly modified, the actual diagrams taken from the engine (reduced to the same scale) at NPQT, XRSY, and UTCDE respectively. Their combined area is 72 per cent. of that of the diagram AFHE′. The deficiencies (as between a perfect engine and actual indicated horse-power) are accounted for by the following losses :—

(1) The cutting-off of the toe of the low-pressure diagram owing to incomplete expansion.

(2) Working steam parting with heat to pistons, covers, and cylinder-walls, which heat is only recovered at a lower temperature, with a less availability for conversion into work.

(3) Leakage of steam past valves and pistons.

(4) Heat from jacket and reheater steam passing into working steam at lower temperatures with the same result as (2).

(5) Radiation from jackets and receivers.

(6) Heat carried away by reheater and jacket drains at a temperature higher than that of exhaust.

(7) Destruction of availability of intermediate-pressure and low-pressure jacket and reheater steam energy through throttling in reducing-valves.

(8) Wire-drawing less mechanical friction.

(9) Clearance losses. The clearances in this engine are so small,

Digitized by Google

and the djustment of the compression point is so accurate, that clearance losses appear to be negligible. The clearances are, however, allowed for in calculations of dryness, etc.

The above losses may be roughly gauged as follows:—The conditions of 1 lb. of the working steam, throughout the engine, as found from test records and from the indicator-diagrams, was plotted on a total heat and entropy diagram (Fig. 4, Plate 4). Of course, this curve cannot be of the highest accuracy, owing to the small scale and the many inaccuracies of indicator-diagrams, to the fact that a diagram may not be representative of the average conditions over the whole test, and also because at no period is the whole of the working steam in exactly the same condition. It probably gives, nevertheless, a very fair guide in computing losses.

A second diagram connecting the entropy and total heat of the whole of the steam (including jacket and reheater steam) is shown in Fig. 5, Plate 4. The height of any point on this curve above the line representing condenser pressure is proportional to the available energy still left in the steam, and the successive steps up this line indicate each individual loss. As before, the total of all these losses is equal to 28 per cent. of the heat-drop available at point A.

In this diagram the heat given up by the live steam in the h.-p. reheater is assumed to be stored without increase of entropy until re-absorbed by the working steam when reheated. Further, heat lost from the jackets is presumed to be retained in the system but with zero availability.

From the point of view also of showing the gain of entropy from entry to exit of each cylinder, that is, its departure from true adiabatic working, the diagram is very graphic. For instance, just before entry to the h.-p. cylinder the steam is as at B. At exit its average is as at X, showing an increase of entropy of 0·01 B.Th.U. per degree. The i.-p. entry is similarly at H and exit at Y, showing a similar increase. Low-pressure steam is as at N at entry and approximately at Z at exit, but in this case after release the thermal condition of the steam is immaterial. The diagram also gives a clear indication of the action of the reheaters and the availability for work at any moment of the heat in the working steam.

From this diagram and the test figures the following results are deduced, the detailed calculations of individual losses being given in Appendix B:—

Loss No. 1.—This is reckoned as the excess, over the work obtained by relief of back pressure, of the available energy of the steam as it would be at the end of a complete l.-p. stroke, assuming all expansion,

Digitized by Google

from release onwards, that it might still do, to be adiabatic. It works out at 10 per cent. of the perfect diagram AFHE′ (Fig. 3).

Loss No. 2.—The period during which heat is passing from steam to metal (in the h.-p. cylinder) is clearly from B′ to D, for at D the expansion becomes isentropic in its change from exothermy to endothermy. The heat given to the metal, at constant pressure, is equal to the change in total heat from B′ to D. This heat is given back from D to F and from G to X, which point is fixed by the fact that, measured as $\int \theta d\phi$, exactly that amount has been returned. There is also an increase of entropy while rushing through the exhaust-valve from F to G. By comparing the availability for work at B′ with the sum of that actually done (as indicated horse-power) and the availability at X on entry to the reheater, a loss of nearly 1·4 per cent. of the perfect diagram AFHE′ is found. By a similar calculation the corresponding loss in the i.-p. cylinder is 2·2 per cent.

In the l.-p. cylinder the toe loss (loss No. 1) already allowed for, leaves only the losses down to end of a perfect l.-p. stroke to be considered, all available heat lost after that being already included in the 10 per cent. of loss No. 1. Thus in calculating this loss the engine is assumed to work perfectly from this point. On this basis the percentage loss No. 2 for the l.-p. cylinder is nearly 1·9 per cent. Each of the above percentages really includes losses under loss No. 8, but the amounts are negligible.

Loss No. 3.—As far as it can be calculated, this loss is included in the above percentages, since its effect is to transfer heat from a higher to a lower temperature. It is assumed that the leakage is too small to affect anywhere the weight of the working steam.

Loss No. 4.—The heat units passing into the heated steam are read from Fig. 4, Plate 4. From the jacket and reheater consumption (and by a knowledge, in the case of the h.-p. reheater, of the drop in total heat of the steam on its way to the h.-p. cylinder), the heat units entering are known. The difference is the radiation loss, and the whole of its availability is lost. The loss of availability of the heat passing into the working steam (in reheaters and jackets) is obtained as for loss No. 2.

The results are :—

High-pressure reheater and jacket loss through transference	2·9 per cent.
Intermediate-pressure reheater and jacket loss through transference.	2·3 ,,
Low-pressure jacket loss whether through radiation or transference	0·2 ,,

Digitized by Google

Loss No. 5.—This is calculated as above; but in the case of the i.-p. cylinder, through some error, none is apparent.

That for the l.-p. cylinder is shown under loss No. 4, since the heat is equally wasted whether transferred to atmosphere or to exhaust steam. The only remaining item is therefore the available energy lost through h.-p. radiation, 2·8 per cent.

Loss No. 6.—This is included in the above, since losses of availability were calculated as though to exhaust temperature, the heat of the water being of no further use to the engine.

Loss No. 7.—The i.-p. and l.-p. jacket steam, being throttled respectively to conditions S and T (Fig. 4), suffers a loss of availability directly readable from the diagram. The quantities of steam used being known, the percentage losses are found to be 0·55 and 0·13, making 0·68 in all.

Loss No. 8.—This results almost entirely from throttling through Corliss valves. Percentage losses are :—

High-pressure steam (from B to B')	Loss = 0·37 per cent.
,, exhaust (unresisted expansion) (from F to G)	Loss negligible.
Intermediate-pressure steam	None noticeable.
,, exhaust (unresisted expansion (from M to M')	Loss negligible.
Low-pressure steam (from N to N')	Loss = 2·0 per cent.
,, exhaust.	The l.-p. cylinder was assumed to make a perfect expansion. Actually, from the indicator cards, it fails to do so by about 4 B. Th. U., which is therefore entirely lost, representing 1 per cent.

The principal losses of available energy appear to be distributed roughly as follow :—

Loss 1.	Incomplete expansion	10·0 per cent.
Loss 2.	Cylinder-wall exchanges	5·5 ,,
Loss 4 and 6	Heat-transference in jackets and reheaters	5·2 ,,
Loss 5	Radiation	3·2 ,,
Loss 7.	Reducing-valves	0·7 ,,
Loss 8.	Wire-drawing	2·4 ,,
		27·0 ,,
Due to early release in l.-p. cylinder		1·0 ,,
	Total Losses	28·0 per cent.
	Indicated Horse-Power .	72·0 ,,
		100·0 ,,

Some of these figures, being calculated as differences, are, no doubt, liable to small errors, especially since there are slight incon-

Digitized by Google

sistencies in the test figures and diagrams concerning which a certain amount of judgment had to be used; but it is claimed that they are a good guide as to what losses may be reducible. Moreover they are, in a measure, checked by their total. Further it should be noted that all these percentages are reckoned on the power of a perfect engine and not on the power actually obtained. Should, therefore, any of them be eliminated, the percentage increase in efficiency would, of course, be greater than the corresponding percentage quoted above.

(B) Conversion of Indicated Horse-Power into Horse-Power in Water Lifted.

The ratio of the water horse-power, measured by displacement, to the indicated horse-power was, under test conditions, 93·6 per cent. It is difficult to allocate the various sources of loss which make up the remaining 6·4 per cent., but the chief components are :—

(10) Friction of bearings, valve-gear, etc.

(11) Power required to drive air-pumps.

(12) Friction of pump-glands.

(13) Friction of water passing through pump-valves and pipes.

Unfortunately, the Author has no figures to enable him to separate losses Nos. 10 and 12, but their approximate sum can be obtained by subtraction.

Loss No. 13.—The official test figures show the pump horse-power, as taken from the pump indicator-cards, to be 532, and the (displacement) pump horse-power 530. Hence the loss due to friction through pump-valves, pipes, etc., is less than 0·4 per cent. of the indicated horse-power.

In this connection it is interesting to compare the indicator-diagrams of the three pumps (Figs. 6, Plate 4). The i.-p. pump does less work than either of the other two. Not only is the suction against it less, but also the delivery pressure is lower. This is due to surge in the suction and delivery boxes and air-vessels.

Loss No. 11.—From the air-pump indicator-cards (Figs. 7, Plate 4) it was found that one of the two pumps was extracting all the air, the valves of the other apparently never opening at all. This was probably due to there being an insufficient accumulation of water over the suction-valves of the latter to fill the clearance space. The quantity of air encountered must, however, have been so small that the one pump could effectually deal with it at a vacuum about 2 inches from the absolute.

The air-pump cylinders are 13 inches in diameter by 4 feet stroke.

Digitized by Google

The indicated horse-power of the working air-pump was 0·3, or 0·06 per cent. of the total.

Thus losses Nos. 10 and 12 are together responsible for nearly 6 per cent. of the indicated horse-power, and the following considerations make it probable that the friction of the mechanism (loss No. 10) is very small.

Figs. 8, Plate 4, though slightly modified from the actual test conditions, very nearly represent the action of this engine. (In this diagram the weights of the reciprocating parts are assumed to be one-half of the water load—which was not, as a matter of fact, exactly realized; and for purposes of calculating inertia effects, the speed was taken at 30 r.p.m.) From the crank-effort diagram of Figs. 8 it is seen that the total work, both positive and negative, which has to be transmitted through the connecting-rods and crank-shaft is only 19 per cent. of the indicated horse-power. (Even this 19 per cent. is calculated on the assumption that all lost power is transmitted to the crank-shaft, whereas of course the gland friction is not.) Thus the friction losses due to power-transmission are very low, and the bulk of the 6 per cent. lost must be due to pump-gland friction.

Slip.—No slip measurements of this plant have been taken. The complete pumps were, however, tested to 300 lbs. per square inch before despatch, when the whole leakage was negligible. For this reason and from the sharpness of valve-closing evidenced by the indicator-diagrams it would seem unlikely that the slip could much exceed 1 per cent.

Any description of the test at Lea Bridge would be incomplete without mention of the excellent results obtained from the steam-raising plant, although the latter is not strictly within the scope of the Paper. Appendix A shows that the equivalent evaporation (from and at 212° F.), including the economizer, was 11·70 lbs. per pound of coal having a calorific value of 15,006 B.Th.U. per pound.

Improvements and Developments.

The efficiency of a steam pumping-plant may be improved in two ways, namely :—

(i) By increasing the ratio of the actual work obtained to that theoretically possible using a perfect plant working under the same conditions.

(ii) By improving those conditions.

(i) Some of the sources of loss which have been discussed may be

Digitized by Google

reduced, and means of effecting these reductions are considered in the following paragraphs.

Loss No. 1.—Incomplete Expansion.—This is one of the points in which a steam-turbine is superior to a reciprocating engine. The Author is now engaged in an effort to recover some of this loss by using a special condenser, but can as yet give no indication as to the likelihood of success.

Loss No. 2.—Cylinder-Metal Heat-Exchanges.—This also is a point of superiority of the steam-turbine, and, to a very much less extent, of the uniflow type of reciprocating engine. In the latter, reheating the piston and cylinder-cover during compression enables the heat-exchanges with those parts to be lessened, but in view of the fact that any portion of the cylinder (in which in the uniflow the whole temperature-drop takes place) can only be heated by compression steam far colder than the live steam which afterwards comes in contact with it, the heat-exchanges with the cylinder-walls can hardly be less than in the triple-expansion engine. This loss in all reciprocating engines is reduced by an increase in speed, which should always be kept as high as the pumps will allow.

Loss No. 4.—Due to Heat Passing from a Higher to a Lower Temperature in Jackets and Reheaters.—This would be reduced if the availability of the heat of the jacketing and reheating steam were more nearly equal to that of the heated steam. An effort in this direction is being made by the use, for i.-p. and l.-p. jackets and reheater, of partly-expanded steam bled from appropriate points. This, of course, necessitates a larger heating-surface for the same amount of reheating. The method really enables some of the heating steam first to reduce its available energy by doing work and so to avoid handing down its highest-grade heat to a lower temperature. The saving under this head might amount to about 2 per cent.

Loss No. 5.—Radiation from Jackets.—This also would be reduced by the foregoing modification, and by increasing the speed. A further saving would probably be made if the l.-p. cylinder were unjacketed, for already much of the heat exchanged with the cylinder metal is only returned to the exhaust steam (R to Z, Fig. 4), and to add to it is mere waste. (A 4-hour test of this engine, with the l.-p. jacket shut off, actually showed better results than those of the official test.) If the jacket could be made hot enough to prevent initial condensation, some advantage would, no doubt, be gained; but failing this, it would appear to be useless.

Loss No. 6.—Destruction of Availability of Jacket and Reheating Steam through Throttling.—This is dealt with under loss No. 4 above.

Digitized by Google

Loss No. 7.—This can only be lessened by keeping all valve-areas amply large, opening and shutting being rapid and accurately timed.

(ii) *Extension of Working Range of Steam.*—The available heat-drop of the steam under the conditions appertaining in the Lea Bridge plant is 355 B.Th.U. per pound. The trend of development of the steam pumping-engine, following that of the generating-station, will undoubtedly be to higher pressures and superheats. This is especially probable in view of the fact that the high-pressure end of the heat-drop is most efficiently utilized by the reciprocating engine. The Author's firm is at present engaged in the manufacture of a pumping-plant of similar type to that at Lea Bridge but working with a pressure of 250 lbs. per square inch and 130° F. superheat. Taking the same vacuum as used in the Lea Bridge engine, the available heat-drop under these circumstances is 373 B.Th.U., or an increase of more than 5 per cent. Yet the temperature, which is perhaps the most decisive limiting factor encountered, is only 32° F. higher than at the test at Lea Bridge. Another scheme of similar type with which the Author was recently associated involved a proposal to use steam at 350 lbs. per square inch pressure and 264° F. superheat, the heat-drop in this case being 435 B.Th.U., or 22 per cent. more than in the Lea Bridge plant. This scheme is, however, still under consideration.

There is thus little doubt as to the direction along which the reciprocating steam pumping-engine will very shortly develop, and, taking all in all, it would appear that improvements in efficiency of the order of 20 per cent. may be expected. On this assumption it is of interest to compare this type with a few of the other classes of pumping-machinery.

Comparison with other Types of Pumping-Machinery.

There are two main types of waterworks pumping-machinery, the reciprocating and the centrifugal. Roughly speaking, for schemes comparable in size with that at Lea Bridge, the centrifugal type holds the field for heads up to about 100 feet and the reciprocating for heads above this figure. It is, therefore, only for these higher heads that a comparison of the various types need be drawn.

Within these limits the main competitors of the Lea Bridge type at present are :—

(1) Oil-engine-driven reciprocating pumps (worked through gearing).

(2) Steam-turbine-driven centrifugal pumps.

Digitized by Google

(3) Ram pumps driven by other types of steam-engine.

(4) Electrically-driven pumps, both centrifugal and reciprocating.

(1) *Oil-Engine-Driven Reciprocating Pumps.*—These have the following advantages as compared with the Lea Bridge type :—

(*a*) Higher overall thermal efficiency.

(*b*) Absence of smoke.

(*c*) Lower labour costs in running.

(*d*) Less space required and lower cost in buildings and foundations.

They have these disadvantages :—

(*e*) Dearer fuel (the price is also subject to violent fluctuations).

(*f*) Less reliability.

(*g*) Starting difficulties.

(*h*) Less flexibility as regards speed.

(*i*) Greater cost in repairs and renewals.

(*j*) Shorter life.

(*k*) Noise, both in engine and gearing.

With regard to initial cost, the Author gives in Table IV, Appendix C, a comparison of capital charges based on a scheme recently prepared by his firm in which the alternatives of steam and oil-engine driving were asked for. As this scheme is to give 370 pump horse-power, it provides a useful comparison with the Lea Bridge type. In the cost of the steam-plant is included that of one water-tube boiler, superheater, and economizer. In neither case are any building costs taken into account.

The fuel costs per pump horse-power-hour under working conditions are given in Table IV, Appendix C. Since the Author has no reliable figures on which to base an estimate of costs of oil and stores, repairs and renewals, and attendance, these are omitted in all cases.

With regard to flexibility, in the scheme considered it is stipulated that the plant must run satisfactorily at any speed down to one-half of full-load speed, so that the superior flexibility of the steam-engine gives it a great advantage in this respect. The main point, however, is reliability, a point in which the steam-engine is greatly superior. In fact, it is usual, when installing oil-engine plant for waterworks stations, to duplicate the engine; but such duplication has not been allowed for in the capital charges in Table IV.

The life of the steam plant has been taken at 25 years; not that it is worn out at the end of that time—one authority reckons the life of such a plant at 40 years—but because by then it may very probably have become obsolete. The life of the oil-engine plant is taken at 15 years, after which time it will have done on an average five times as many revolutions as the steam-engine in 25 years.

Digitized by Google

Producer gas-engines should also be mentioned under this head. They are free from some of the above-mentioned objections, but they have the following additional drawbacks :—

(*l*) They have usually to stop for a certain period daily for cleaning.

(*m*) They are liable to smell badly.

(*n*) Their capital cost tends to be high, since an equally powerful engine is larger, and there are many auxiliaries.

Town-gas engines are free from these objections, but the cost of their fuel is generally prohibitive.

(2) *Steam-Turbine-Driven Centrifugal Pumps.*—These also have the drawback of being driven through gearing, but they have the following advantages :—

(*a*) They occupy very little space and cost but little in buildings and foundations.

(*b*) They need less supervision.

Their disadvantages as compared with the Lea Bridge type are :—

(*c*) Higher steam-consumption.

(*d*) Less flexibility.

(*e*) Shorter life and quicker deterioration of efficiency.

(*f*) Less reliability, since a small defect may wreck the whole turbine.

For purposes of comparison of fuel and capital costs two comparative instances are taken, one from a station in which an 871-pump-horse-power turbine-driven set is installed as a standby to the reciprocating set of equal power, and one of 313 pump horse-power, in which the two run alternatively. In both cases it will be seen that the advantage rests with the reciprocating plant.

It should also be pointed out in connection with (*d*) above that a turbine-driven centrifugal set will give considerable variations in delivery if required, but, as compared with the reciprocating type, its efficiency falls off rapidly when not delivering against its normal load.

(3) *Ram Pumps driven by other types of Steam-Engine.*—There are so many varieties under this head, that it is impossible to compare them all with the Lea Bridge type. Of direct-acting plants none can give better efficiencies than the vertical triple-expansion type, nor is there any which, under ordinary circumstances, presents more marked advantages as to compactness. A compound engine is sometimes cheaper, but the saving in first cost is generally overbalanced by the increased fuel-consumption.

There are a few cases in which a direct-acting uniflow engine has come into competition with a triple-expansion type, and one

Digitized by Google

comparative example is given in Table IV, Appendix C. The steam-consumption is higher than that of the triple-expansion engine. The merit of simplicity claimed for the uniflow engine is counterbalanced by the very heavy nature of the mechanism, which has really to be strong enough to take the whole steam-pressure on an area corresponding to that of the l.-p. piston of a triple-expansion engine. In fact, the uniflow mechanism partakes of the nature of that of a gas-engine. Further, having regard to the probable development in steam range in the future, the uniflow engine, which is really capable of making good use of the middle portion only of the range, is not likely to come much into use for direct-connected pumping work.

The high-speed steam-engine has frequently been used, in conjunction with gearing, for waterworks pumping. One comparative example is given in Table IV. The steam-consumption per pump horse-power is higher than for the Lea Bridge type, but the lower capital cost may make its adoption worth while in certain instances, especially where the plant may be of a temporary nature.

(4) *Electrically-Driven Pumps, both Centrifugal and Reciprocating.*—The main objection to the use of electricity for large pumping-units is, in most places, the very high cost of the current. Table IV gives the cost per pump horse-power-hour using a ram pump and also using a centrifugal pump, the figures referring to a waterworks station where the two are installed as alternatives. Apart from cost of power, electric driving has the following disadvantages :—

(*a*) Dependence on an outside source of power, involving risks of breakdown, labour troubles, etc., in a separate establishment.

(*b*) With alternating current, very little flexibility as regards rate of delivery from ram pumps, or in the case of centrifugal pumps a falling-off in efficiency if the normal load is departed from.

(*c*) Less reliability than steam plant.

(*d*) Shorter life than steam plant of the Lea Bridge type.

And the following advantages :—

(*e*) Comparatively small space and foundations required.

(*f*) Absence of smoke and dirt.

(*g*) Improvement, in certain cases, of load-factor of generating-station.

(*h*) Less labour required for supervision, though more skilled.

From Table IV it is thus seen that the cost (of fuel and capital spent on machinery) is normally less for the Lea Bridge type than for any other. In addition to this the relative advantages and disadvantages of other kinds of pumping machinery cited above weigh on the whole on the side of the Lea Bridge type. There would

Digitized by Google

seem, therefore, to be good reason to conclude that it is not likely in the near future to be ousted from its present pre-eminent position in the realm of large-scale waterworks pumping.

The Author desires to express his gratitude to Mr. H. E. Stilgoe, M. Inst. C.E., and to the Engineering Staff of the Metropolitan Water Board, for their kindness in allowing him to use the test results obtained on the Lea Bridge plant, and for the help they have invariably given him in obtaining all data, etc., that he has at any time required.

The Paper is accompanied by six sheets of diagrams from which Plate 4 has been prepared, by a sheet of test results, and by the following Appendixes.

[APPENDIXES.

Digitized by Google

APPENDIX A.

Boiler Test Results.

Nos. 52 and 53 Lancashire Boilers supplying Musgrave Engine.

Duration—9 hours.

Fuel. Nixon's Navigation Large.		Lbs.	Per cent.
Per hour fired		688	100
Per hour less grate loss		653	95·0
	combustible		95·9
of combustible	Carbon		89·7
	Hydrogen		4·3
	Sulphur		1·0
	Oxygen		5·0
	Fixed carbon		87·7
	Volatile		12·4
of fuel as fired	Carbon		85·9
	Fixed carbon		84·0
	Volatile		11·9
	Ash		2·0
	Moisture		1·5
Calorific value as fired, B.Th.U. per lb.		15,006	
Ash and Clinker.			
Ash and clinker per hour—Total		53	7·7
Laboratory ash per hour		18	2·6
Lbs. of coal in ash and clinker per hour		35	5·1
Lbs. carbon per hour		30	
Lbs. of coal per sq. ft. of grate-surface		9·55	
Flue Gases.			
Carbon dioxide			11·2
Carbon monoxide			0·0
Oxygen			7·4
Nitrogen			81·4
Air and Draught.			
Temperature air	°F.	76	
Temperature gases leaving boiler	,,	534	
Temperature-rise	,,	458	
Draught over fire	inches of water	0·09	
Draught at main flue	,,	0·4	
Average thickness of fire	ins.	4½	
Feed-Water.			
Pounds per hour		6,630	
Temperature to economizer	°F.	124	
,, from economizer	,,	197	

Digitized by Google

Steam.		
Gauge-pressure	lbs. per sq. in.	188
Degrees of superheat	°F.	124
Equivalent factor		1·217 1·147
Furnace Gases.		
Products of combustion per pound of fuel burnt	lbs.	12·1
Excess air per pound of fuel burnt . .	,,	6·8
Total chimney gases per lb. of fuel burnt	,,	18·9
Products of combustion per lb. of fuel fired, less grate loss	,,	11·5
Excess air per lb. of fuel fired, less grate loss	,,	6·5
Total chimney gases per lb. of fuel fired, less grate loss	,,	18·0

Heat Account per pound.	B. Th. U.	Per cent.
Calorific value	15,006	100·0
Generating steam—efficiency boiler only . . .	10,710	71·5
Hydrogen burnt to steam instead of water . .	374	2·5
Carried away by products of combustion . .	1,264	8·5
,, by excess air	714	4·8
,, by moisture in fuel	17	—
Incomplete combustion	0	—
Unburnt carbon in ash and clinker	632	4·2
Insensible heat of clinker	15	—
Radiation	1,030	7·0
Total		98·5
Balance unaccounted for or excess	230	1·5

Firing.		
Fuel per sq. ft. of grate per hour . . .	lbs.	10
Evaporation.		
Actual evaporation per pound of coal . .	lbs.	9·65
Equivalent evaporation from and at 212° F.	,,	11·10
Do. do. including economizer .	,,	11·70

APPENDIX B.

Calculation of Individual Losses.

Loss No. 1. Toe of Indicator Diagram.—This is taken as the availability still left in the steam, assuming the l.-p. expansion to be carried to the end of the diagram adiabatically from release. At release of l.-p. cylinder the pressure is 5·9 lbs. per square inch absolute at 0·88 stroke. Hence dryness = 0·919, and total heat = 1,052 B.Th.U. If expansion is made adiabatically to 5·15 lbs. per square inch absolute, dryness (from Mollier chart) = 0·912. Therefore the ratio of expansion is 1/0·88 nearly, so that this would be the pressure arrived at at the end of the stroke. From the chart the total heat is then 1,043 B.Th.U., and the total heat after adiabatic expansion thence to 27·8 inches (the test vacuum referred to 30 inches barometer) = 953 B.Th.U., therefore the available energy at this point (1,043 B.Th.U. at 0·912 dryness) = 91 B.Th.U. per pound.

Digitized by Google

By measurement of the indicator diagram, the actual energy obtained by relief of back pressure below 5·15 lbs. per square inch = $94·6 \times (5·15 - 1) \times 144/778$ B.Th.U. per stroke, but working steam per stroke = 1·44 lb., therefore back-pressure energy per pound of working steam = 50·6 B.Th.U., and loss due to incomplete expansion = 40·4 B.Th.U. per pound. The available energy for a perfect engine = 355 B.Th.U. per pound of working steam. Total working steam in perfect engine = 1·632 lb. per stroke.

$$\text{Therefore, percentage loss} = \frac{40·4 \times 1·44}{355 \times 1·632} = 10 \text{ per cent.}$$

Loss No. 2.—From the ϕI diagram, the heat passing into the h.-p. cylinder, piston, etc., from B′ to C = 118 B.Th.U., being equal to the drop in total heat (at constant pressure), or calculated as $\int \theta d\phi$. And from C to D, the point where the heat changes its direction of flow, heat units out, from entropy change, = 2 B.Th.U. Hence total transference of heat = 120 B.Th.U. per pound of working steam.

Assuming that the steam cannot increase its entropy save by absorbing heat, the heat re-entering up to release at F is found by taking $\int_F^D \theta d\phi$.

At D θ = 830° abs. . . . . } Mean = 802·5° abs. $\delta\phi$ = 0·04
At E θ = 775° abs. . . . . }
At F θ = 739° abs. . . . . } Mean = 757° abs. $\delta\phi$ = 0·044

Therefore heat restored from D to F = 32·1 + 33·3 = 65·4 B.Th.U. This leaves 120 − 65·4, = 54·6 B.Th.U. to be transferred during exhaust at constant pressure. Hence total heat at X, when all heat is restored, is 54·6 B.Th.U. higher than at G.

To fix G, the diagrams show that the average drop from release to exhaust = 4½ lbs.

Therefore the work done by relief of back pressure = 7 B.Th.U., and the total heat at G is 7 less than at F. The pressures of F and G are taken from the cards and gauge-readings.

Hence X is fixed at a total heat of 54·6 − 7, i.e. 47·6, above that at F.

(*Check.*—From the chart the net heat-drop in the h.-p. cylinder down to release = 32 B.Th.U. The net heat entering the steam in the same time = 63·4 B.Th.U. Therefore the work done down to release should be 95·4 B.Th.U. Actually from the cards it scales 98 B.Th.U.)

From the chart the available energy at X . . . . . = 224 B.Th.U.
And work actually obtained (from cards) . . . . . = 105 ,,
Therefore the total of work obtained and still obtainable . . = 329 ,,
But had perfect expansion occurred from B′, without heat-exchange or sudden expansion, it would have been 333 B.Th.U.
Hence loss of available energy in h.-p. cylinder due to heat-exchanges and sudden expansion . . . . . = 4 ,,

From the chart only, not assuming the card value of work obtained, this would scale, from gain of entropy, 7 B.Th.U. Hence it will perhaps be best to take an average value of 5·5 B.Th.U. loss per pound of working steam.

As a percentage of the heat-drop of a perfect engine this is

$$5·5 \times 1·44/355 \times 1·632 = 1·4 \text{ per cent. nearly.}$$

Digitized by Google

Intermediate-pressure Cylinder.—Heat-drop H to K = 40 B.Th.U., and from K to L approximately 2 B.Th.U., making a total heat-transference of 42 B.Th.U. From L to M the entering heat = 32 B.Th.U., got as follows :—

θ abs. at L . . . . . = 729° } Mean = 714° $\delta\phi$ = 0·024
θ abs. at 10 lbs. gauge . . . = 699° }
θ abs. at M . . . . . = 669° } Mean = 684° $\delta\phi$ = 0·022

Hence 42 − 32 = 10 B.Th.U. remain to be communicated to the steam after M′.

From the diagrams, the work done by the relief of back pressure = 12 B.Th.U. Therefore height of Y, where all heat is returned, above M = −2, or total heat at Y is 2 B.Th.U. less than at M.

(*Check:* Heat-drop K to M = 54 B.Th.U. Net heat entering K to M = 30 B.Th.U. Therefore work done during expansion should be 84 B.Th-U. It is actually, from cards, 78 B.Th.U.)

Available energy at Y = 1,104 − 961 . . . . . = 143 B.Th.U.
Work actually done in cylinder . . . . . = 90 ,,
Therefore energy obtained and obtainable . . . = 233 ,,
A perfect engine working from H would have given . . = 245 ,,

Therefore loss = 12 B.Th.U.

From the chart only, not assuming card value of work done, this would scale 6 B.Th.U.

Hence, taking average, as for h.-p., the loss = 9 B.Th.U.

Thus intermediate-pressure loss due to heat-exchange and sudden expansion . . . . = { 2·2 per cent. nearly of heat-drop of perfect engine.

Low-pressure Cylinder.—The toe loss already allowed for under Loss No. 1 leaves only the losses down to release to be considered, everything after that having been assumed to be perfect. If the engine had worked perfectly from point N′, the available energy would have been 1,160 − 1,019 = 141 B.Th.U. Actually, it works perfectly from release, R, only, when the available energy is still 1,052 − 953 = 99 B.Th.U.

And the energy actually obtained (from card) down to release . . . . . = 34·6 B.Th.U.
Therefore the total energy obtained and still obtainable (though mostly actually wasted) . . . . . = 133·6 B.Th.U.

Hence loss = say 7·5 B.Th.U., so that

Loss in l.-p. cylinder due to heat-exchanges = { 1·9 per cent. of heat-drop of perfect engine.

Hence total loss due to heat-exchanges and sudden expansion (exclusive of l.-p. release) . . . . . = 5·5 per cent.

A further loss due to sudden expansion in the low-pressure cylinder in place of the perfect stroke assumed amounts to about 4 B.Th.U. from the diagram, or 1 per cent.

Loss No. 4.—h.-p. Reheater and Jacket.—From the chart, heat units passing into heated steam from X to H, at constant pressure, $= I_H - I_X = 87$ B.Th.U.

This heat is obtained (1) by cooling all live steam, and (2) by condensing some.

All live steam (1·13 lb. per pound of working steam) is cooled from A to B in the h.-p. reheater, thus heat out = 54 B.Th.U. per pound, or 61 B.Th.U. per 1·13 lb., i.e., per pound of working steam.

Digitized by Google

By measurement of the h.-p. jacket and reheater discharge, the weight of steam condensed from B per pound of working steam = 0·0656 lb. Hence heat from steam condensed = 0·0656 × (851 + 17) = 56.9 B.Th.U. per pound of steam.

Hence total heat units entering = 118 B.Th.U. per pound of working steam.

Total units absorbed in reheater = 87 B.Th.U. (above).

Therefore units radiated and lost in jacket = 31 B.Th.U. per pound of working steam.

Increase of availability of steam heated from X to H = 1,200 − 955 − (1,113 − 889) = 21 B.Th.U.

Loss of availability of all steam (1·13 lb.) cooled from A to B = 1·13 × (355–335) = 22·6 B.Th.U.

Loss of availability of (56·9 − 31) × 0·0656/56·9 lbs. of steam condensed in reheater, assuming all the available energy lost, since the hot water is of no further use to the engine = 25·9 × 0·0656 × 335/56·9 = 10·1 B.Th.U. per pound of working steam.

Hence net loss of availability = 32·7 − 21 B.Th.U. due to heat-exchanges in h.-p. reheater, = 11·7 B.Th.U. per pound of working steam, = 2·9 per cent. of perfect engine.

Intermediate-pressure Reheater and Jacket. — From the chart the heat absorbed from Y to N at constant pressure = $I_N - I_Y$ = 56 B.Th.U. The experimental measurement of the i.-p. jacket and reheater drain discharge was unsatisfactory owing to losses of both water and vapour due to the force of ejection from the trap. But by subtracting total of the h.-p. jacket and reheater and the l.-p. jacket drain discharges from the total jacket and reheater discharges taken on the official test, the i.-p. jacket and reheater discharge = 0·051 lb. per pound of working steam.

The heat extracted from this steam per pound in condensing from state S = 892 + 29 = 921 B.Th.U., or for 0·051 lb. = 47 B.Th.U. per pound of heated steam.

There is thus a deficiency of 9 B.Th.U. per pound without making any allowance whatsoever for jacket radiation losses. But in the actual test the l.-p. jacket pressure was 7·2 lbs. per square inch, whereas in the jacket consumption test it was 30 lbs. per square inch. Hence there is little doubt that in the actual test the l.-p. jacket consumption was lower and the i.-p. higher than that given.

An i.-p. consumption of 56 × 0·051/47, or 0·061 lb. per pound of working steam, is therefore assumed, which will just supply the heat required in the reheater. The amount 0·01 lb. per pound of working steam is subtracted from the l.-p. jacket consumption.

Then increase of availability from Y to N = 152 − 143 = 9 B.Th.U. Decrease of availability of 0·061 lb. of condensed steam from state S, the heat in the water being, as before, of no use to the engine = 0·061 × 298 = 18·1 B.Th.U. per pound of working steam.

Therefore loss of available energy in i.-p. reheater = 9·1 B.Th.U. = 2·3 per cent. of heat-drop of perfect engine.

Hence total loss under this head = 5·2 per cent.

Loss No. 5. Radiation from Jackets.—The whole of the availability of heat so radiated or conducted is lost. In the case of the h.-p. cylinder (Loss No. 4, above) 31 × 0·0656/56·9 lbs. per pound of working steam loses all its available energy from state B. Therefore the loss = 31 × 0·0656 × 335/56·9 = 12 B.Th.U. per pound of working steam.

Digitized by Google

Hence h.-p. jacket loss = 3·0 per cent. of heat-drop of perfect engine.

On the figures taken there is no loss from the i.-p. jacket.

From the l.-p. (p. 233) a loss is assumed of all available energy in 0·0147 − 0·01 = 0·0047 lb. per pound of working steam from state T.

Available at T per pound = 1,215 − 1,010 = 205 B.Th.U.

Therefore loss per pound of working steam = 0·97 B.Th.U. = 0·2 per cent. of heat-drop of perfect engine.

Thus total loss under this head = 3·2 per cent.

Loss No. 7. Throttling of Jacket Steam.—Availability at B = 335, at S = 298. Therefore destruction per pound = 37 B.Th.U. Weight per pound of working steam = 0·061, therefore heat lost = 2·25 B.Th.U. = 0·55 per cent. of heat-drop of perfect engine.

Availability at T = 205 B.Th.U., therefore destruction per lb. = 130. Weight assumed per pound of working steam = 0·0047 lb.

Therefore heat lost per pound of working steam = 0·61 B.Th.U. = 0·13 per cent., making a total under this head of approximately 0·7 per cent. of heat-drop of perfect engine.

Loss No. 8. Throttling during Admission.

High Pressure.

From B to B′, from the chart, the loss of available energy = 1·5 B.Th.U. or 0·37 per cent. of perfect heat-drop.

Intermediate Pressure.

This is negligible.

Low Pressure.

From N to N′, from the chart, the loss of available energy = 8 B.Th.U. per pound of working fluid, or 2 per cent. of perfect heat-drop.

Hence total loss due to throttling during admission = 2·4 per cent.

Total of all Losses, per cent.

Loss 1	10·0	of heat-drop of perfect engine.
Loss 2 and 3	5·5	,, ,, ,,
Loss 4 and 6	5·2	,, ,, ,,
Loss 5 and 6	3·2	,, ,, ,,
Loss 7	0·7	,, ,, ,,
Loss 8	2·4	,, ,, ,,
		,, ,, ,,
	27·0	,, ,, ,,
Due to early release in l.-p. cylinder	1·0	

Calculation of heat still to be returned to steam after l.-p. release.

From N′ to P heat out of steam . . . . = 38 B.Th.U.

From P to Q change of entropy . . . . = 0·078. Mean θ = 648° abs.

Therefore heat out P to Q . . . . = 50·5 B.Th U.

Heat in Q to R . . . . . = 631 × 0·015 = 9·5.

Therefore total heat-input N′ to R . . = 79 B.Th.U., which is to be returned after expansion to Z.

Digitized by Google

APPENDIX C.

Table IV shows the cost of fuel (or electric power) and the interest and sinking fund on capital, but does not include allowance for stores, repairs, renewals, and attendance.

The following assumptions are made :—

(1) *Fuel.*—The prices are assumed as follows—

Coal—of 13,000 B.Th.U. quality	£1 per ton.
Oil—of 18,000 „ „	£5 per ton.
Electricity	1d. per unit.

(2) *Boiler-Efficiency.*—Where not otherwise known taken at 70 per cent. For efficiency calculation the feed-water is taken at—

For Reciprocating Plant	100° F.
For Steam-Turbine Plant	70° F.

(3) *Steam-Losses.*—In all steam plant 10 per cent. of the steam-consumption has been allowed for steam-losses (radiation, leakage, etc.), and a further 20 per cent. of this total for banking and auxiliaries.

(4) *Slip.*—Where unknown, slip has been allowed at 2½ per cent.

(5) *Capital Costs.*—These are correct for present date (March, 1926). They do not include foundation work or buildings.

For steam plant one set only of steam-raising plant is included. For oil-driven plant no standby oil-engine is included.

(6) *Money.*—Taken at 5 per cent. for calculating interest and sinking fund.

(7) *Life.*—The lives of the different types of machinery have been taken as follows :—

Slow-running steam reciprocating engine and pumps. .	25 years.
High-speed steam reciprocating engines and gearing . .	15 „
Oil-engines and gearing	15 „
Steam-turbines and centrifugal pumps	10 „
Steam-raising plant	20 „
Electrically-driven reciprocating pumps	15 „
Electrically-driven centrifugal pumps	10 „

(8) *Running Hours.*—Taken at 8,000 hours per annum.

Digitized by Google

TABLE IV.—SCHEDULE OF COMBINED FUEL AND CAPITAL COST FOR DIFFERENT TYPES OF PLANT. COST RECKONED PER WATER HORSE-POWER-HOUR.

Type.	Nominal Duty.		Water Horse-Power.	Steam-Supply.		Cost per Water HP.-Hr.			Remarks.
	Quantity.	Head.		Pressure.	Superheat.	Fuel.	Capital.	Totals.	
	Million Gals. per 24 Hrs.	Feet.		Lbs. per Sq. in.	°F.	Pence.	Pence.	Pence.	
Vertical triple-expansion steam-engine and force-pumps (Lea Bridge)	14·0	200	519	181	124	0·165	0·106	0·271	Test. No allowance for banking.
Vertical triple-expansion steam-engine and force-pumps	9·6	183	370	250	150	0·191	0·091	0·282	Estimate
Crude-oil semi-Diesel engine driving force-pumps through gearing	9·6	183	370	—	—	0·281	0·072	0·353	Estimate
Vertical triple-expansion steam-engine and force-pumps	17·5	236	871	200	100	0·206	0·091	0·297	Estimate
Steam-turbine driving centrifugal pumps through gearing	17·5	236	871	200	100	0·255	0·054	0·309	Estimate
Vertical triple-expansion steam-engine and force-pumps [1]	7·9	188	314	180	80	0·236	0·088	0·324	Test. Banking &c. Losses added
Steam-turbine driving centrifugal pumps through gearing	7·9	188	314	180	80	0·359	0·076	0·435	Estimate

[1] Engine large enough to drive a set of 110-W. HP. low-lift pumps in addition.

Digitized by Google

TABLE IV.—SCHEDULE OF COMBINED FUEL AND CAPITAL COST FOR DIFFERENT TYPES OF PLANT. COST RECKONED PER WATER HORSE-POWER-HOUR.—*continued.*

Type.	Nominal Duty.		Water Horse-Power.	Steam-Supply.		Cost per Water HP.-Hr.			Remarks.
	Quantity.	Head.		Pressure.	Super-heat.	Fuel.	Capital.	Totals.	
	Million Gals. per 24 Hrs.	Feet.		Lbs. per Sq. in.	°F.	Pence.	Pence.	Pence.	
Vertical triple-expansion steam-engine driving borehole and force-pumps	1·34	542	156	250	130	0·219	0·165	0·384	Estimate
Uniflow engine direct coupled to borehole and force-pumps	1·34	542	156	180	150	0·274	0·181	0·455	Estimate
Uniflow engine driving borehole and force pumps through gearing	1·34	542	156	180	150	0·302	0·137	0·438	Estimate
Vertical triple-expansion steam-engine and force-pumps. (Same as above). . . .	9·6	183	370	250	150	0·191	0·091	0·282	Estimate
Triple-expansion high-speed engine driving force-pumps through gearing	9·6	183	370	250	150	0·268	0·070	0·338	Estimate
Electrically-driven three-throw ram pumps .	4·0	253	209	2,000 volts	2 phase	0·981	0·079	1·060	Test
Electrically-driven two-stage centrifugal pump	3·0	270	171	2,000 volts	2 phase	1·066	0·039	1·105	Estimate
Electrically-driven quadruple-acting ram pumps	0·83	4,200	740	2,200 volts	3 phase	0·825	0·020	0·845	Test

Digitized by Google

Discussion.

The President. The PRESIDENT, in moving the vote of thanks to the Author, remarked that he intended to adhere to the rule he had laid down for himself when taking office, and would avoid the temptation to anticipate the discussion; but he wished to say that it was not usual for The Institution to receive from one of its junior Associate Members a Paper of the standard of that before the meeting, dealing so efficiently with a subject of great importance to the engineering world generally. He would like, on behalf of The Institution, to congratulate the Author on the work he had put before the members that evening. The Author was apparently working in a direction which involved a great many interesting problems, and he felt sure the members would be benefited if the Author were able, as his experience ripened, to bring the subject before them again as years went on.

The Author. The AUTHOR, in describing some lantern-slides, remarked that in the test described there was bound to be a certain amount of approximation. The test had not been carried out with a view to the analysis which he had attempted to apply to it, and it was not absolutely complete for the purpose for which he had used it. He hoped that in the near future tests would be carried out on other engines, notably the one at Walton, of the Metropolitan Water Board, when perhaps it would be possible to obtain more accurate results, even though calculated by means of differences. He hoped that a too literal interpretation would not be put on the decimal figures of his losses, in view of the fact that the test was not really made *ad hoc*. The guarantee was for steam at 190 to 195 lbs. per square inch pressure and 75° to 100° F. superheat, compared with the test figures of 181 lbs. per square inch and 124° F. superheat. Those two sets of conditions, however, represented identically equal availability under the condenser conditions obtaining at Lea Bridge; and, although the results of the test had not been got under precisely the same conditions as those on which the guarantee was based, they had been obtained on equivalent conditions.

Mr. Smith. Mr. ROGER T. SMITH remarked that, as a pupil of Messrs. Hathorn, Davey & Company, who made and erected the pumping-engine described in the Paper, he had assisted in the erection of the first pumping-engine they put up at Lea Bridge 37 years ago. That

Digitized by Google

engine pumped from a deep chalk well and was arranged for both sinking and permanent pumping. While he was there it generally ran at one stroke in 3 minutes. A pump arranged in that way could not possibly be efficient as a waterworks pumping-engine, so far as its consumption of coal was concerned. The economic reason for the arrangement was that it saved pumps in the first case, and, secondly, at the moment the well was sunk, the permanent pumping was ready to begin. So far as he was aware, the Paper was the only one in the English language in which an attempt had been made—and a very successful attempt—to assign in the case of a steam pumping-engine values to the various losses which made up the differences between the efficiency of the perfect engine and the actual efficiency. By means of the entropy-diagram that analysis had been fully and convincingly worked out. It was doubtful whether the gain in steam-economy to be obtained by increasing the working range of the steam, as proposed by the Author, would be justified. He did not mean that it was not possible to improve the efficiency of the engine in that way, but it was necessary to take into consideration the troubles in the boiler-house and the extra expense in labour and maintenance on boilers working with pressures as high as 350 lbs. per square inch. He endorsed what the Author said, that *for its size* the modern triple-expansion reciprocating pumping-engine was in terms of £. s. d. easily the most economical engine for converting the heat of fuel into work. A pumping-engine of 500 HP. would be considered big, but the steam-turbine did not attain the same efficiency until it was of at least ten times that size in output. The steam turbine was the more economical the higher the vacuum, but it was doubtful if it paid to run the reciprocating engine with as high a vacuum as was maintained at Lea Bridge. It was probable that any vacuum above 26 inches of mercury was not worth the getting, partly because of the very large size of the low-pressure cylinder (and its consequent extra radiation) which was necessary in order to use so high a vacuum. On the other hand, the waterworks, or sewage, or drainage pumping-engine was unique in providing itself with ample condensing water, and the money spent in obtaining the vacuum was almost negligible. He thought the Author might legitimately have claimed, as one of the intrinsic economies of the waterworks pumping-engine, that the condensing water cost nothing. The possibility of an ample supply of water generally decided the site of a large electric power-station; and the pumping of what was the equivalent of a small river through the condensers, the necessary training works, and means of cleaning the water, were

Mr. Smith.

Digitized by Google

Mr. Smith. often very costly. In Table IV the fuel charges and the capital charges on plant alone were compared for test figures—not running figures—either actual or estimated, for various sorts of pumps and pump drives. Since in most cases the figures taken were estimates, he preferred to compare the Lea Bridge pump, as it might be made for an electric drive with a higher speed and therefore smaller pumps, with the actual results of the test of the Lea Bridge engine. The Author assumed the cost of electricity to be 1*d.* per unit for a load-factor of 91 per cent. The average selling-price in 1925 for all the power-companies in this country, however, was 0·9*d.*, with a load-factor ranging about 30 per cent., and any power-company in this country, if asked to supply electricity for a load-factor of 91 per cent., would be able to do it at ½*d.* per unit, most of them at 0·4*d.* per unit. Assuming that at Lea Bridge there was a smaller pumping-engine driven by a three-phase motor through gearing, the average cost throughout the year—not a special test figure—of electricity corresponding to the coal per horse-power-hour would be 0·84*d.* with electricity at 1*d.* per unit, 0·42*d.* with electricity at ½*d.* per unit, and 0·33*d.* with electricity at 0·4*d.* per unit. Secondly, the real gain in the case of electric drive lay in just those figures which the Author had omitted from Table IV—the cost of labour and the capital charges, not only on plant but also on buildings, to which must be added rates, taxes, maintenance and management. If he understood the Author's method of calculating capital charges, which appeared to come to about 6 per cent. on the Lea Bridge engine, that pump would cost about £30,000, and the foundations and buildings about £10,000. He would be very glad if the Author could give the actual figure. With electrically-driven pumps, the plant and buildings would be little more than a quarter of that figure, and the attendance charges one-quarter of the Lea Bridge labour charges, or even less if hand-fired boilers had to be maintained at the efficiency of 70 per cent. which the Author assumed. Without the labour charges, but including the whole of the capital charges, he claimed that in the neighbourhood of any power-company's distribution-system, the power-company selling electricity at 0.4*d.* per unit for that special case, the total working-cost, taken all the year round, of an electrically-driven pump would be about the same as that of the Lea Bridge pump. Taking into account the labour charges, the electrically-driven pump would actually show a slight saving over the steam-driven pump, and there would be the advantage of getting somewhere about the same total working-cost for an expenditure of one-quarter of the capital that was necessary to install the steam-driven pump.

Digitized by Google

Mr. A. P. I. COTTERELL observed that the figure given for steam-consumption per pump horse-power-hour—10·6 lbs.—was extremely low and satisfactory, and, judging the plant by the coal consumed per pump horse-power-hour, the figure of 1·3 lb. was also very good indeed. A few years ago, when he was advising a corporation on new pumping-plant, he was told it was a retrograde step to recommend, as he did, the introduction of steam pumping-plant, instead of extending the existing suction gas-plant. The installation was to be equal to pumping at least 60,000 gallons per hour, or 1,440,000 gallons per diem, a total lift, including friction, of 413 feet, of which 135 feet was lift from a borehole by borehole pumps and 278 feet the head from the surface tank to the reservoir. He made a careful comparison between the cost of steam pumping-plant, similar to that described in the Paper, and of a suction gas-plant of the same capacity. He assumed the suction gas-plant to be fitted with a rope drive to a counterbalanced borehole pump, and to work horizontal three-throw ram pumps. The annual cost of the steam plant, apart from capital outlay, per actual pump horse-power worked out at £13 10*s*. 10*d*., as against £15 12*s*. 9*d*. for the suction gas-plant. An estimate of running-costs, including capital charges and loan repayments over a period of 15 years, showed that there was practically no difference in annual outlay between the steam plant and the suction gas-plant, but, of course, the steam plant had the advantage that its life would undoubtedly be much longer. He had seen plants 50 or 60 years old still in use and apparently in good mechanical condition, but they were so obsolete so far as their consumption of steam was concerned that on that ground alone it paid to renew them. The corporation to which he had referred had adopted his recommendation and put in a steam plant constructed and erected by the Author's firm. After the plant had been in service for a few months, a test was carried out by Professor Andrew Robertson, Assoc. M. Inst. C.E. The results obtained were not as good as those given for the Lea Bridge engine, but they were more than equal to the makers' guarantee. The steam-consumption per pump horse-power-hour was 12·04 lbs. per hour, the mechanical efficiency was 91·7 per cent., and the coal-consumption per pump horse-power-hour was 1·68 lb. The superheat was 123° F., and the actual steam-temperature on the engine side of the stop-valve was 502·8° F. Fig. 3, Plate 4, showed that the high-pressure and intermediate-pressure diagrams overlapped. Was that overlapping area included, or was it regarded as lost? With regard to improvements possible by increasing pressure and superheat, he agreed with Mr. Roger

Mr. Cotterell.

Digitized by Google

Mr. Cotterell. Smith in doubting whether it was really possible to obtain higher efficiency by increased superheat. A test[1] of the pumping-engines at Hamburg, erected, he believed, in 1922, provided an interesting comparison. Those engines were not quite of the same type as the Lea Bridge plant, but were very nearly comparable. The temperature at the stop-valve ranged from 572° F. to 662° F. The steam-consumption per indicated horse-power-hour ranged from 10·36 to 10·67 lbs. The mechanical efficiency appeared to be about 90 per cent., which would give a steam-consumption of about 11·7 lbs. per pump horse-power-hour. He would like to hear the Author's further comments on that, because his own impression had been, until he saw those figures, that improvement by reduction of loss in the prime mover in question would lie in the direction of increased superheat. With regard to the useful comparison the Author had made in Table IV, he agreed that the cost of electricity had been put rather too high. In the case of the comparison he had made between suction gas and steam plant, the cost of fuel for suction gas was 31*s.* per ton, and for the steam engine 23*s.* per ton, with a calorific value of about 14,000 B.Th.U. per pound. For large units steam still held its place and was likely to continue to hold it. There were cases where another type of plant could be usefully employed, even with a large unit, but only under special conditions. For smaller units, however, and especially for distinctly small units, the other types referred to in Table IV would be better than, or quite as good as, steam. The last had not been heard of the crude-oil engine. His own impression, however, was that the use of steam for the pumping of water was not yet by any means antiquated.

Mr. Bryan. Mr. B. W. BRYAN observed that in the Lea Bridge test the weight of coal used per pump horse-power-hour was 1·3 lb. The coal used was Nixon's Navigation Welsh large steam. He thought the price of that coal in bunker would not be less than about 38*s.* per ton. That would make a cost on the test of about 0·265*d.* per water horse-power-hour with an admittedly superior class of coal. The Author showed a price of £1 per ton for coal of 13,000 B.Th.U. per pound, and there was no doubt that in the vicinity of the coal-fields that would be correct. On the other hand, in London coal cost more. He had some particulars of actual running-costs of triple-expansion engines taken over a period of 16 years, finishing in 1925. The plant was a triple-expansion engine in duplicate,

[1] *Zeitschrift des Vereines deutscher Ingenieure*, vol. 68, p. 277. "Engineering Abstracts," No. 20, p. 132.

Digitized by Google

working well-pumps through gearing. The maximum power of each engine was about 190 B.HP. There was no superheat and there were no economizers. The continuous water horse-power throughout the whole 16 years was 159 HP. For a considerable period the two engines would be running a portion of the day together. One of them might be said to have run continuously, with a few hours intermission, throughout the 16 years. Coal cost 0·397*d.* per water horse-power-hour; wages, 0·251*d.*; maintenance, including repairs, 0·033*d.*; and stores of all sorts, including gas for lighting the station, 0·030*d.*; making a total of 0·711*d.* per water horse-power-hour throughout the whole period. The average weight of coal burnt throughout the year was 1,714 tons, and the average cost, including cartage, was 26*s.* 11½*d.* a ton. The coal used per water horse-power-hour was 2·75 lbs., and the duty per 112 lbs. of coal was 80·5 million gallons. It was interesting to compare that with a 100-B.HP. suction gas-plant over the same 16 years. The continuous water horse-power, however, was only 25½ HP. The engine ran 10 to 15 hours a day, so that conditions were not conducive to economy. The maintenance cost 0·15*d.* per water horse-power-hour, and the stores 0·12*d.* The maintenance was therefore about five times as high, and the stores about four times as high, as was the case with the steam plant. The water horse-power of the steam plant during 1925 was 136 HP., and the cost of coal for that year was 24*s.* 11*d.* a ton; in other words, it was 2*s.* cheaper than the average for the 16 years. The reason for that was that towards the close of the war, and for 4 years after the war, the undertaking with which he was connected was buying extremely expensive coal and at the same time developing the maximum output of which its station was capable, because the war had precluded development of its other works. When coal prices were at their maximum, the pump horse-power was about 260 HP., as compared with 135 HP. for 1925—a very high load-factor thus coinciding with very high coal-prices.

Mr. Bryan.

Mr. H. E. STILGOE remarked that, having regard to the fact that the engine in question had been constructed for the Metropolitan Water Board, of which authority he had the honour of being the Chief Engineer, and also in view of the fact that the Author's firm were constructing other and larger engines for the Board's Walton works, he was somewhat diffident about entering upon a discussion of the Paper. It might be of interest, however, if he gave a few particulars of the operation of steam pumping-engines. The Board had one hundred and fourteen groups of engines, some containing one in a group and some two or three. He had, therefore,

Mr. Stilgoe.

Digitized by Google

Mr. Stilgoe. an opportunity to compare the work of various engines. In selecting a type of engine for a particular class of work, consideration had been given to the circumstances under which the engine was going to run. Some of the engines ran for more than 90 per cent. of the time, and naturally had to be selected with a view to their efficiency for work of that kind. The engines which were now being constructed by Messrs. Hathorn, Davey & Company for the Walton works were of 945 pump HP. Those engines were practically completed; in fact, they had been under steam. It had been found that the triple-expansion engine of the type at Lea Bridge was the one most suited to pumping day in and day out throughout the year, when the plant had to be of 250 HP. and

TABLE V.—OPERATING COSTS FOR YEAR ENDING 31 MARCH, 1925.

Engines.	No. of Units.	Type.	Power Per Unit.	Water Pumped Per Unit.	Cost Per Pump Horse-Power-Hour: Pence.				
					Coal.	Wages.	Repairs.[1]	Stores.	Total.
			Water H.P.	Million Gall. Per Diem.					
Riverdale (Hampton)	3	Triple expansion	510	9	0·47	0·15	0·06	0·20	0·70
Moreland's	2	Compound	510	9	0·46	0·22	0·17	0·04	0·89
Nos. 13, 14 and 15 (Hammersmith)	3	No. 13, compound	195	3	0·35	0·26	0·10	0·04	0·75
		No. 14 and 15 triple expansion	430	7 and 10	..	..	..	..	..

[1] Including wages and materials allocated to repairs.

upwards, and also when it was necessary to pump up to heads exceeding 150 feet. He thought that the Board had as complete a record of working-costs as was kept by any undertaking in this country. They had the figures of cost in respect of practically every engine. In one or two instances there were two or more engines in a group, and the cost could not very well be separated for each engine; so, being of similar type, the engines were taken together. He thought Table V would be interesting in respect of engines in operation for a great number of years. The Riverdale engines—which were constructed 27 years ago—had been running for 97 per cent. of the year. He had been told that during the war one of those engines ran for 4 years, day, night, and Sundays, without stopping. They had required very little repair, except that 2 years

Digitized by Google

ago the cast-iron entablatures carrying the cylinders showed signs of slight cracking. Whether that was due to fatigue or vibration he could not say, but new entablatures had been put in. Those engines to-day were running as well as they had ever done The Moreland engines were built 41 years ago. A new crankshaft was fitted to one of the engines and new main bearings to both, which accounted for the higher figure (0·17*d.*) for repairs executed during the year. Complete records were kept year by year in tabular form of the performance of each engine. The various engines were classified in order of merit, by districts and by types, in order of total cost per pump horse-power, in order of actual fuel per pump horse-power, and in order of duty corrected to coal of 15,000 B.Th.U. quality, and so on. That method of keeping statistics gave a good opportunity to ascertain what type of plant was most suitable for each type of work. Whether the number of hours worked was taken into consideration, or the capital cost, or any other factors, he was able to arrive at an estimate of the best type for any particular purpose. Mr. Stilgoe.

Mr. ARTHUR HONEYSETT observed that he had had considerable experience of the kind of engine described in the Paper, having during the last 20 years assisted in the installation of nine such engines of powers ranging from 150 to 450 water HP. and pumping against heads of 55 to 390 feet. The total power exceeded 3,000 water HP., and the combined capacity of the pumps was 88 million gallons per day. This type of engine was chosen in the first place, 20 years ago, after careful inquiry as to the merits of the different forms which were then obtainable. The result of that inquiry was that the type of engine in question was found to present advantages over all others as regarded both first cost and economy in working. Subsequent experience had fully justified the choice. The engines were still working and were apparently as good as ever. They had been maintained in repair by the ordinary engine-staff, and no events had occurred calling for the intervention of the makers. The cost of repairs averaged 40*d.* per million gallons pumped, equivalent to 1 per cent. per annum upon the capital value of the engine. The steam-consumptions guaranteed were 13 lbs. per pump horse-power-hour for the low-lift engines (55 to 70 feet) and 11·9 lbs. for the high-lift engines (188 to 390 feet). These figures had been well maintained, a consumption as low as 10·7 lbs. having been noted on some occasions with the high-lift pumps. This was in striking agreement with the Author's figure of 10·6 lbs. He had recently had the opportunity of testing the Mr. Honeysett

Digitized by Google

Mr Honeysett. slip of some of those engines, after about 15 years of continual work, by counting the revolutions necessary to fill up a reservoir of known dimensions and comparing the quantity of water stored with the displacement of the pump-plungers. The result was a slip of $2 \pm 0{\cdot}3$ per cent., the maker's guarantee having been 3 per cent. He was in agreement with the general result given in Table IV as to the relative economy of the various methods of pumping, but he suggested that the Table did not tell the whole story, since the load-factor of the pumping-plant was not considered. If all the machinery were to work 24 hours per diem, there would be nothing to be said against the figures, but such was seldom the case, and in pumping for water-supply purposes it was generally very far from the truth. It was, therefore, not the sum, but the ratio of expenditure upon capital to that on fuel which was of importance. As the load-factor diminished, the relative merits of a cheap but inefficient centrifugal pumping-plant came more and more into evidence, resulting in an entire superiority when the extreme case of a purely stand-by unit was reached, since this was seldom or never brought into use, and its high fuel-consumption was of but little importance. He had recently had occasion to look into this question in considerable detail, as it had become necessary, in one of the pumping-stations he had referred to, to increase the pumping power by bringing into use the engine which until then had been regarded as a stand-by. It then became necessary to install a new stand-by engine, and, on account of the improvements which had of late years been effected in centrifugal pumps, turbines, electric motors, and high-speed engines, attention was naturally directed to the employment of some such device in place of the continued use of the highly efficient but also very expensive reciprocating engines of the class which the Author had described. Careful estimates were made, based upon thoroughly reliable information, of the total cost of pumping by each of the following methods:—(1) High-class reciprocating engines; (2) centrifugal pumps and turbines; (3) centrifugal pumps and high-speed steam-engines; (4) centrifugal pumps and motors taking electricity from the public supply; and (5) centrifugal pumps and motors driven by electricity specially generated. A simple method of determining the relative merits of any scheme was to calculate the number of hours which the cheap but less effective machine must run per annum for the total annual cost to become equal to that of the dearer but more efficient machine. The higher the figure so obtained, the greater was the overall economic merit of the scheme. Thus, if the triple-expansion engine described in the Paper were taken as the standard, and

Digitized by Google

the best of each of the other combinations were taken, the result was as follows— Mr. Honeysett.

2.	Centrifugal pump and turbine . . .	hours 1,330
3.	,, ,, ,, high-speed engine . .	,, 1,030
4.	,, ,, ,, public electricity (a.c.) .	,, 600
5.	,, ,, ,, private electricity (d.c.)	,, 360

Thus, when a centrifugal pump was used, a steam-turbine formed the best means of driving it, and such a combination was more economical than a high-class reciprocating engine, so long as the time which it had to work did not exceed 1,330 hours per annum. For any longer period the lower coal-consumption of the high-class engine more than balanced the greater charge for interest. The figures on which the foregoing conclusion was based were shown in the following Table—

QUANTITY OF WATER PUMPED.

330,000 gallons per hour to		188 feet
363,000 ,, ,, ,, ,, ...		62 ,,
Total W.HP. 426·66.		
Cost of engine.		£18,000
Cost of steam		26 lbs. per penny
Steam per water horse-power-hour		11·8 lbs.
Total steam per hour.		5,100 lbs.
Cost of steam per hour		212 pence
Cost of steam for 1,330 hours	£1,170	
Amortization for one year at 1½ per cent. Interest for one year at 1½ per cent. .	1,170	
		£2,340
Cost of turbines		£6,000
Steam per water horse-power-hour		18·71 lbs.
Total steam per hour.		8,200 lbs.
Cost of steam per hour		342 pence
,, ,, ,, for 1,330 hours	£1,895	
Interest for one year at 5 per cent. . Amortization for one year at 2½ per cent.	450	
		£2,340

The cost of keeping the machinery in repair was omitted in both cases, as it was assumed that it would be proportionate to the work done, and therefore not materially different in the two instances. The case investigated was for machinery installed in a foreign country where fuel was expensive. In this country the comparison would be more favourable to turbines, and the result was also greatly affected by the size of the plant, since large turbines were much more economical than small ones. For instance, if the cost of fuel were one-half that which he had assumed, and if the cost of transport

Digitized by Google

Mr. Honeysett. were deducted from the capital charge, the figure of 1,330 hours would be increased to slightly more than 2,000; and further, if the size of each unit were doubled, the figure would become 3,750 hours. The last was rather an extreme case, but not an impossible one, and it might therefore be taken that the superiority of the triple-expansion engine was always apparent when the load-factor exceeded 40 per cent., but was not likely to be apparent when it fell below 15 per cent. Increases proportionate to that from 1,330 to 2,000 would apply to the other examples, including the electrical pumping, since the cost of electricity in the locality to which the estimates applied was about double that prevailing in this country. In cases (3) and (4), however, no increase of importance would take place as a result of doubling the size of the units.

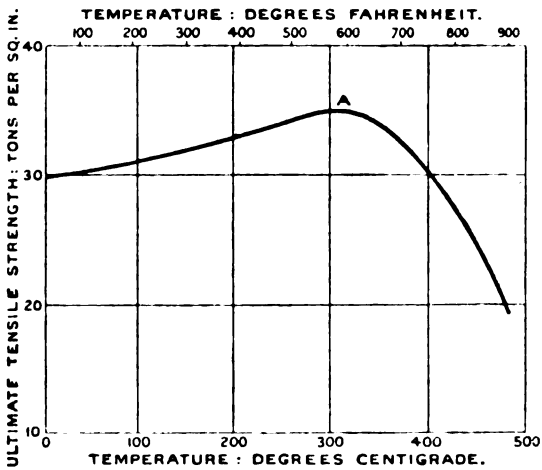
Mr. Thwaites Mr. R. A. S. THWAITES observed that, in comparing the cost of the plant used at Lea Bridge with electrically-operated plant, the Author made certain comparisons based on electricity at 1*d.* a unit for a 90-per-cent. load-factor. The Author came from Leeds, and therefore Mr. Thwaites had taken the Leeds maximum-demand tariff and had found that for the last three examples given at the bottom of Table IV (p. 237) the price per unit, according to that tariff, came out, not at 1*d.*, but at 0·475*d.*, 0·5*d.*, and 0·375*d.* per unit respectively. That gave an average total cost, including capital charges, as compared with the figures given by the Author, of 0·544*d.*, 0·572*d.*, and 0·33*d.* per water horse-power-hour respectively. There were two matters in regard to the cost of steam on which he thought the Author had taken a somewhat optimistic view. A boiler efficiency of 70 per cent. seemed high for the conditions in question. Mr. David Brownlie had recorded[1] that tests on 88 boiler-plants with mechanical stokers and more than 300 plants which were hand-fired showed a boiler efficiency, including superheaters and economizers, of 60 per cent., which he thought would be a fairer figure. The Author also had assumed rather a low price for coal, seeing that most pumping-plants were a good distance from railway-stations or sidings; 23*s.* per ton would be a fair average price, and if a correction were made on those accounts, the total costs per water horse-power-hour for the steam plant shown in Table IV (pp. 236–7), should be 0·445*d.*, 0·64*d.*, 0·54*d.*, 0·34*d.*, and 0·47*d.* respectively. The average of those figures gave 0·48*d.* for steam plant, which was the same as that given by Mr. Thwaites for electricity; but, in addition to that, as had already been pointed out, the Author omitted the very items which were in favour of electric driving,

[1] Proceedings Inst. Mech. E., 1920, p. 263.

Digitized by Google

namely, buildings, foundations, repairs, maintenance, and labour. He thought, therefore, that the Author was a little sweeping in his statement that there was no real competitor with the triple-expansion engine in the field of pumping. In support of this, Mr. Thwaites might state that the power-company with which he was associated had recently made two large contracts for supplies of electricity for water-pumping, one for 24 hours a day, and the other for 8 hours a day. He was convinced that electricity would prove a very serious rival to the steam pumping-engine, whether for short-period use, or for continuous pumping. The main reason was that with generating sets of 15,000–20,000 kilowatts, the standing charges per horse-power were only a fraction of the corresponding charges for a steam pumping-plant. Mr. Thwaites.

Fig. 9.



The PRESIDENT observed that the Author mentioned a proposal to use a pressure of 350 lbs. per square inch and a superheat of 264° F. He wished to allude to the knowledge which had been gained as to the behaviour of steel at the high temperature—approaching 400° C.—involved in boilers operating under such conditions. Taking, for example, a 30-ton steel, *Fig. 9* showed that it was perfectly safe up to, but not beyond, 400° C., which was about the equivalent of 500 lbs. per square inch pressure and 250° F. superheat. Now that very much higher pressures and superheat temperatures were being adopted, engineers, in calculating boiler stresses, must realize that at point A of the diagram the strength of the material began to be adversely affected by the superheat temperature. The President.

Digitized by Google

Correspondence.

Mr. Clark

Mr. G. M. CLARK observed that there was sometimes confusion between the efficiency of an engine and the efficiency of the steam cycle of supply. The efficiency of a practical engine was a function of the ratio of expansion and diminished with the increase of this ratio. That was to say, for the same type of engine it was an easier matter to obtain an efficient engine, as measured by the ratio of work produced to available energy, with a low ratio than with a high one. Thus, to increase the efficiency of an engine it was not correct to increase the pressure and superheat and improve the vacuum; the heat-drop must be reduced so as to reduce the ratio of expansion. With triple-expansion engines working from, say, 200 lbs. per square inch pressure to a vacuum of 2 lbs. per square inch, the ratio of expansion was 100 to 1, but with a turbine working from 350 lbs. to 0·7 lb. per square inch the ratio was 500 to 1. Hence it was easier to get a high efficiency, say 70 per cent., for the engine than it was to get, say, 65 per cent., for the turbine; and the efficiency of the engine would be improved by making the steam conditions worse. At the same time the engine gave a smaller output, and it was the weight-output factor, or the price-output factor, that controlled the practical efficiency. In a cycle of supply it was the efficiency of supply that was improved by raising the pressure and superheat and improving the vacuum. This efficiency of supply (a term that was not used as much as it might be) was the ratio of the available energy in the steam to the total heat reckoned from the water state at the temperature of the vacuum. The heat-drop was shown on the Mollier diagram and was controlled by the difference of temperature in the boiler and in the condenser.

Neither the Mollier diagram nor the $T\phi$ diagram could give the efficiency of the engine, but from them could be found the efficiency of supply of the cycle used. This on the $T\phi$ diagram was the ratio of the area H_a above the condenser temperature line T_2 to the whole area, H_a, of the diagram that showed the successive state-points for the steam cycle used. The area below the line of T_2 was the heat

Digitized by Google

rejected, H_r. The efficiency of supply was the ratio H_a/H_s which was $(H_s - H_r)/H_s$, or $1 - H_r/H_s$. But H_r was equal to $T_2\phi$, where ϕ was the increase of entropy, so that the efficiency was Mr. Clark.

$$1 - T_2\phi/H_s, \text{ or } 1 - T_2/(H_s/\phi).$$

But the last expression H_s/ϕ was the area of the diagram divided by its length ϕ, and on the analogy of the PV diagram in which the area divided by the length was the mean effective pressure, so on the $T\phi$ diagram the mean effective temperature was T_m, and the efficiency of the cycle of supply was $1 - T_2/T_m$.

If an example were worked out for a superheating cycle, it would be seen how little the mean effective temperature was raised and how small a primary influence superheating had upon the efficiency of supply. There were, however, secondary effects on the efficiency of use, such as the dryness of the walls in a reciprocating set and the postponement farther down the blading of the dew-point in a turbine, that were of greater value. As touching this value of superheating, it was often confused with the gain on the engine when the boiler was left out, but it must be considered with the boiler taken in, as coal had to be burned to superheat the steam, and, further, when this was done, the entropy was increased and the theoretical gain became very small indeed. For ordinary working-pressures about 200 lbs. per square inch absolute 100° F. would give on the cycle of supply a gain of 5 per cent., but it would take 3 per cent. to heat the steam from saturation to the total temperature, so that on the cycle the gain would be 2 per cent. only. Taking the feed-water temperature to the boilers as that of the vacuum in the engine exhaust, (1) the efficiency of production as given by the boiler was the ratio of the total heat in the steam, reckoned from this level, to the heat of combustion of the fuel; (2) the efficiency of supply as given by the condenser was the ratio of the heat available to the total heat in the steam; and (3) the efficiency of use as given by the engine was the ratio of the work done to the heat available. The overall efficiency was the running product of the three and was the ratio of the work done to the heat of the fuel.

The engine did not make the heat-fall any more than a water-wheel made the waterfall, and the cycle of energy operation could be looked upon as being boiler–condenser–engine instead of following the cycle of the matter as boiler–engine–condenser. From an improved cycle of supply an engine was given a greater available energy to operate upon, but the practical difficulty lay in making

Digitized by Google

Mr. Clark. an engine which could operate on this larger supply with the same efficiency that it could on the smaller. As the ratio of expansion increased it became necessary to change the type of engine in order to maintain the efficiency, and just as simple and compound engines had their limits of efficiency, so, too, had the triples, and the type must be changed to turbines when the ratio of expansion was still further increased. The term ratio of expansion might be either the ratio of decompression p_1/p_2, or the ratio of increase in volume V_2/V_1, and a comparison could be made for an equal ratio of expansion on either basis. For example, with steam at 350 lbs. per square inch absolute exhausting into a vacuum of 3·5 lbs. per square inch, the ratio of expansion p_1/p_2 was 100 to 1, and this was the same as for a cycle operating between 200 lbs. per square inch and 2 lbs. per square inch. If in the former case the steam was superheated to 600° F. and in the latter to 580° F., then the ratio of expansion would also be the same for the two cases when defined as the change in volume V_2/V_1.

The comparison of these two sets of conditions was :—

		(A)	(B)
(1)	Steam-pressure, ... lbs. per sq. in. absolute	350	200
(2)	Temperature of saturated steam . . . . . °F	432	382
(3)	Final superheated temperature . . . . . °F	600	580
(4)	Degrees of superheat . . . . . °F	168	198
(5)	Back-pressure, ... lbs. per sq. in. absolute	3·5	2·0
(6)	Ratio of expansion (1)/(5)	100	100
(7)	Heat for steam-production, . . B.Th.U. per lb.	1,203	1,225
(8)	Available heat . . . . . „	352	348
(9)	Heat rejected to condenser. . . „	851	877
(10)	Efficiency of supply (8)/(7) . . . . per cent.	29·3	28·4
(11)	Reciprocal of (10)	3·42	3·52
(12)	Ratio of A to B in (11) . . . . . per cent.	97	—
(13)	Specific volume at inlet, . . . cubic ft. per lb.	1·72	3·01
(14)	Specific volume at outlet . . . „	85	148
(15)	Ratio of expansion (14)/(13) . . . . per cent.	49·4	49·2

Thus for two sets of conditions chosen so as to make the ratio of expansion the same in pressure (6) and in volume (15) the advantage to the extent of 3 per cent. (12) lay in the use of higher pressures in production and supply of the steam, and there would be further advantages in use in the engine.

Mr. Fairley. Mr. WILLIAM FAIRLEY observed that the Author, in making comparisons (p. 226), stated that "Town-gas engines are free from these objections, but the cost of their fuel is generally prohibitive," while on p. 227, in dealing with electrically-driven pumps, he raised

Digitized by Google

no objections to the fuel-costs; it would be interesting to know the grounds for thus dismissing town-gas-driven plant. Mr. Fairley agreed with the Author that with large units steam was invariably the most economical in fuel-cost, but he had generally found town-gas plant more economical in fuel-costs than electrically-driven plant. At a station on the Thames with units of 6 to 10 million gallons per day the fuel-cost for town-gas plant connected by gearing to centrifugal pumps was 0·35*d.* per 1,000 gallons lifted; in the same station with electrically-driven motors, direct coupled to centrifugal pumps, the cost was 0·39*d.* per 1,000 gallons lifted. The lift in both cases was less than 40 feet; the price of gas was 4*s.* per 1,000 cubic feet, and electric power 1·14*d.* per unit. Mr. Fairley.

Mr. G. E. HIDER observed that the Paper constituted one of the very few attempts to analyse the thermal action of a high-class reciprocating engine. It was remarkable that many classical experiments had been carried out on engines of bad design, which rendered the alleged results open to grave doubt because many factors, other than those it was sought to investigate, were of unknown magnitude, and wrong assumptions might easily have crept in. Mr. Hider.

As he had recently stated in a Paper read before the South Wales Branch of the Institution of Mechanical Engineers criticizing the uniflow engine, the history of the reciprocating engine was remarkable. First there had been the single cylinder engine using very wet steam; then the steam was superheated to do away with condensation losses; next, due to lubrication difficulties the superheaters were scrapped and the multiplication of cylinders was resorted to; then superheaters were reintroduced; and finally the uniflow engine reintroduced the single-cylinder engine. These were the steps in the evolution of the reciprocating engine, and he considered justified the conclusion that there had been much confusion of thought.

He was interested to find that the Author produced results showing that for powers of about 600 I.HP. better results might be obtained with counterflow engines than with uniflow engines. The Author, in dealing with improvements and developments, also referred to the steam-turbine and the uniflow engine, and stated that, with regard to the heat-exchange between metal and steam the steam-turbine, and to a very much less extent the uniflow type, were superior to the counterflow type.

He questioned whether the heat-exchange in a uniflow engine was less than in a well-designed counterflow engine: it

Digitized by Google

Mr. Hider. certainly was difficult to find any evidence in practice, and it was equally difficult to explain why condensation would be very much less in that type of engine, because the temperature and pressure of the steam were undergoing cyclical variations which were sensibly uniform throughout the whole steam space; the turbine was the only unit in which there was no reason for alternate give and take of heat at any point between admission and exhaust, because each part of the metal was continually in contact with steam of unvarying temperature. The very slight advantage in steam-economy of the uniflow engine could be more than accounted for by the elimination of receiver losses and by the ideal arrangement of exhaust allowing instantaneous reduction to condenser pressure; these facts threw grave doubt on the claims made that condensation losses were less in this type of engine. The Paper showed that at last the design of the reciprocating engine was receiving scientific consideration. The combination of diagrams in Fig. 3, Plate 4, showed that full consideration had been given to the question of receiver losses: the complete agreement between the back-pressure line of one diagram and the initial pressure in the following cylinder was remarkable, and showed that the Author had his finger on one of the vital weaknesses of multi-cylinder engines. Mr. Hider assumed that that was due to the use of Corliss valves, and the only doubt was whether that type of valve remained permanently tight or whether there would not be a gradual falling-away as the valves began to wear. It was interesting to note that better results were obtained when the low-pressure jacket was cut out, and that clearances were very small and the adjustment of compression very accurately arranged, the latter being another vital phase of engine-design, usually neglected, but which constituted one of the essential factors contributing to the economy of the uniflow engine. He wondered whether the extreme jacketing and reheating which was arranged for was justified, and whether a consumption of 9·92 lbs. of steam per indicated horse-power-hour could not be obtained by less expensive arrangements. With regard to incomplete expansion, he had put into operation in conjunction with Messrs. Davey, Paxman & Company, Ltd., of Colchester a method of effectually reducing this loss by by-passing steam towards the end of expansion to the other side of the piston to fill up the clearance spaces. This, of course, was merely a partial solution, but many extensions of the principle were possible. If the Author would search further into the weaknesses of the uniflow engine, he would discover the essential points

Digitized by Google

in the usual design of that engine which led to economy, namely, the hot end, small clearances, and ideal exhaust, in which the potential energy of the steam at release was converted into kinetic energy; and if he embodied those features in a counterflow engine, he would be able to eliminate many of the thermal complications which the arrangement at Lea Bridge possessed, without sacrificing economy. Either three high-pressure cylinders designed with hot ends, small clearances, and rational exhausts, or one high-pressure cylinder dealing with the upper part of the pressure-range and exhausting into two low-pressure cylinders, would give very low steam-consumption, especially if the by-pass principle were embodied, or some modifications of it which allowed of the utilization of the heat contained in the steam at the later part of expansion, just before release. Finally, it was interesting to read a Paper which did something to call a halt to the "uniflow" worship which appeared to be the fashion nowadays, and for which there was no justification except that in the past British engine-builders had violated many first principles and had thus contributed to the apparent success of the uniflow engine, which clearly owed its small advantages in steam-consumption to features apart from the steam-flow arrangements. Mr. Hider.

Mr. T. D. KEY remarked that in the case of the Lea Bridge engine the losses occurring between the engine stop-valve and the condenser appeared to have been reduced, when compared with the very similar type of engine under his charge and belonging to the Alexandria Water Company, by reduced cylinder-clearances, more accurate distribution of the steam in the cylinders, and better design of the steam-passages and receivers. He thought the direction in which still further economies could best be obtained was in the use of higher initial steam-pressures at moderate superheat. In connection with the Author's estimate of the cost per water horse-power of other types of pumping plant, Mr. Key had a few comparative figures, showing the difference in working-costs of steam-driven pumps of the Lea Bridge type, as against reciprocating pumps driven by Diesel engines through gearing. At the Alexandria Water Company's Rond-Point works were installed six pumping-sets of the Lea Bridge type and two sets of similar reciprocating pumps driven by Diesel engines through gearing. All those pumps drew water from the same source and delivered into the same rising mains; the steam and the Diesel-driven plants were, however, housed in separate buildings and each had its own staff of engine-drivers and assistants. Pumping was continuous throughout the 24 hours, the staffs being divided Mr. Key.

Digitized by Google

Mr. Key. into three 8-hour shifts. Careful records of the working-costs had been kept over a number of years, and the following was a summary for the two years 1923–1924 :—

	Steam Plant.	Diesel-driven Plant.
Total work done : million foot-tons	2,782·68	3,393·34
Average price of fuel per ton . .	£2 15*s*. 2*d*.	£5 8*s*. 7½*d*.
Cost per million foot-tons of work done :—		
	£	£
Fuel	5·185	1·597
Stores	0·071	0·192
Maintenance, repairs, and spare parts . .	0·183	0·323
Wages	1·335	0·182
Total	£6·774	£2·294

The Lea Bridge engine on the 9 hours test used about 0·61 ton of coal per million foot-tons of work done, or just about a quarter of the fuel-consumption given above. Taking the official test figures of one of the steam-engines at Rond-Point as a basis of comparison, the fuel-consumption should not exceed 0·9 ton of coal per million foot-tons of work done, and yet from the figures given above for the 2 years' working, the coal actually used was more than twice that quantity. The difference seemed enormous, and yet after careful inquiry he was by no means convinced that any very different result could be obtained under actual working conditions. The principal causes leading to higher fuel-consumption than that given on the basis of test figures were : (1) Intermittent working, with heat-losses every time the engines were started or stopped ; (2) banking fires in the boilers during periods of low pumping output ; and (3) blowing down, cleaning, and again raising steam in the boilers. Those losses were inevitable, and in a plant where the units were many and comparatively small, their importance was correspondingly great. There were also other losses, which could be avoided, but whose importance was generally greater than the above, namely : bad stoking, leaky drains and steam-taps, valve-gear out of adjustment, and leakage past valves and pistons. To obviate those losses a highly trained and keen engineer should be on each shift, and such men could not economically be employed on a small plant. The greater part of the discrepancy between test figures and those actually obtained in running practice was mainly due to the inferior quality of the coal. The calorific value of the coal used in the Lea Bridge test was 15,000 B.Th.U. per pound. Coal of that quality was unobtainable in Alexandria. A nearer approximation to the mean average calorific value of the best Welsh coal obtainable

Digitized by Google

there was about 9,500 B.Th.U. per pound; and a large portion of the coal sold for steam-raising purposes was of even lower calorific value. He appreciated the fact that it was unfair to debit a steam-engine with anything except the heat supplied to it, but at the same time it should never be forgotten that the steam-user had to buy and pay for coal by weight and not on its heat value. Mr. Key.

The greatest defect of the Diesel engine used for pumping purposes was its liability to cause awkward situations. A very small fault often necessitated an engine of this class being brought to a standstill at a minute's notice and before any preparations could be made to put additional pumps into service; and if, as at Rond-Point works, the rate of pumping depended largely upon the number of filters at work, efficient arrangements must be made to throw filters out of action immediately an unexpected stoppage took place. Apart from this inconvenience, however, it appeared that the advantages were on the side of the internal-combustion engine. With that class of machine the losses occasioned by bad stoking were entirely eliminated, and it might almost be said that the fuel-consumption was independent of the engine-room staff. It was true that adjustment of all moving parts in the engine must be more carefully attended to than in a steam-engine, but that in reality was an advantage, in that small defects must be immediately remedied, whereas in a steam-plant the temptation was always to put off the evil hour and keep the engine running, with consequent loss of efficiency. One of the disadvantages attributed by the Author to the use of oil-driven pumping-plant was "less flexibility as regards speed." That was a point which should not be passed over without comment—at any rate as far as the Diesel engine was concerned. All the Diesel engines under Mr. Key's charge were fitted with a speed-regulating device whereby the speed of the engines would be immediately and easily reduced from their rated speed of 250 revolutions per minute to 160 r.p.m., and any engine-maker would fit that small accessory at a cost of a few pounds. His considered opinion was that when Diesel engines were to be used for waterworks purposes it would be better if the engine-maker, even at the risk of unfavourably affecting his price per horse-power, reduced the speed of the engine to say 10 per cent. below the normal rating for its type. The price per horse-power was increased, but the client would benefit enormously by freedom from stoppages and in the reduced cost of renewals.

Mr. Arnold Maude observed that the high efficiency of the ram pumps and the excellent way in which the low-speed steam- Mr. Maude.

Digitized by Google

Mr. Maude. engine was adapted to drive them with very small transmission losses certainly placed this combination in an extremely strong position, though the schedule (Table IV), would have shown centrifugal pumps in a somewhat better light than it did, if building and foundation costs were allowed for and also if a longer life than 10 years were assumed for them. There certainly were many centrifugal pumps which had worked on heads of the order in question for well over 10 years, the renewals, if any, being confined to inexpensive sleeves and bushes. Of course, steam-turbines could show a similar record, though there had sometimes been considerable deterioration of the blading—a trouble which should practically disappear with the adoption of stainless steel. If the wide adoption of turbo gear drives for powers of the order in question had been too recent to make it possible to point to many such gears of 10 years life, examination of gears that had run for 6 or 7 years certainly did not suggest a 10-year limit. The fact that the largest individual loss in the Lea Bridge engine was the toe of the low-pressure diagram suggested the possibility of a gain by substituting a turbine, driving a centrifugal pump, for the low-pressure cylinder, with a corresponding reduction in the ram pumps. An approximate result was—

Total pump horse-power, Lea Bridge test, 530
„ indicated horse-power „ „ 566, of which 184 horse-power was due to the low-pressure cylinder.

The pump horse-power due to the low-pressure cylinder was assumed to be $184 \times 530/566 = 172$ HP. (this was not quite fair to the turbine, since the high-pressure end of the reciprocating engine was the more efficient). For simplicity, taking steam at point N, Fig. 4, Plate 4, allowing for a drop to turbine to, say, 10 inches vacuum and 20° superheat, and adopting a condenser vacuum of 28·75 inches which, with ample cooling water, should be possible except in very hot weather, the heat-drop was 174 B.Th.U. With an efficiency of 79 per cent. for the pump and 66 per cent. for the turbine and gear, the consumption worked out at 28 lbs. per pump horse-power-hour, so that the 4,967 lbs. of steam which passed through the engine-cylinders should yield 177·5 pump horse-power from the turbo pump, that was, about 3 per cent. more than the 172 HP. assumed to be due to the low-pressure cylinder. It would seem worth consideration, therefore, whether possible savings in capital cost, particularly if building and foundation costs were allowed for, would not make this an attractive combination. The diversity of

Digitized by Google

the plant might be considered to be a disadvantage; on the other hand, in an emergency, either part of the plant could be run alone, so reducing need for stand-by plant. The combination of reciprocating engines and exhaust-steam turbines had, of course, been successfully used in electric power-stations and for ship-propulsion. Mr. Maude.

Mr. J. H. MAWSON remarked that there were one or two points in the trial figures (Tables II and III) upon which comment might be made. The difference between the quantity of feed-water to the boilers and the steam used by the engine was 1,012 lbs. per hour, or 18 per cent. of the steam used by the engine. That difference was ascribed to the consumption of boiler feed-pumps and other auxiliaries. Could it not have been reduced by fitting the boiler feed-pumps to the main engine? The temperature of the feed-water entering the boilers appeared to be rather low, and the saving due to the economizer was only about 5 per cent. He would be glad to know if any reason could be given for that moderate result. It was to be regretted that no meter had been available to measure the water pumped. The Author considered that the slip probably did not exceed 1 per cent., but it was doubtful whether the evidence of the pump indicator-diagrams could be accepted on this point. Leakage past the valves could occur which would not be apparent on the diagram. His experience was that slip was generally more than was anticipated, and that a meter was very desirable, both for the duty trial and afterwards as a regular check on the pump efficiency. With regard to the analysis of losses in the cycle, the most serious, and apparently the only one which could be attacked with much hope of success, was the 10-per-cent. loss through the cutting-off of the toe of the low-pressure diagram. In that connection the Author stated that he was experimenting with a new condenser, but, presumably, any result achieved thereby would only be to widen the limits between which the engine worked, by improving the vacuum. More complete expansion (using the toe of the l.-p. diagram) could only be obtained by greater cylinder-capacity, that was, by using larger cylinders with earlier cut off throughout, or by adding a fourth cylinder. As the Author remarked, much more was to be gained by increasing initial pressure, and it appeared clear that pressures would increase until the point was reached where further gain in thermal efficiency was offset by the increasing practical mechanical difficulties incidental to the higher temperatures. It was difficult to see how this limiting point could be found, except by some sort of trial-and-error process. The comparison of various types of pumping-plant given in Table IV Mr. Mawson.

Digitized by Google

Mr. Mawson. was doubtless reasonably accurate as far as it went, but it covered only a small part of the ground which must be reviewed when a choice as to type of pumping-plant was to be made. The number of types available was so large, and local conditions influenced the choice to such an extent, that every separate scheme must be considered on its own merits. It was safe to say, however, that under suitable conditions there was no type of plant which would prove more reliable or more economical in fuel than that described in the Paper.

The Author. The AUTHOR, in reply to the Discussion and Correspondence, remarked that the main point of criticism, raised by several speakers, was that he had taken, in his comparisons of running-costs, much too high a price for electric power. Electric pumping reminded him of Savery's engine as applied to the driving of machinery. That engine pumped water, and the water ran over a water-wheel and worked various appliances in his workshop. An electric drive in which a steam-engine pumped alternating current through a main, and that alternating current worked a motor driving a pump, had distinct points of analogy. It might be that power could, in many places, be obtained at a cheaper rate than 1*d.* per unit, and many authorities stated that its price was likely to be reduced in the future. According to the Electricity Commissioners the average price over the whole country might be expected by 1940 to be reduced to 1*d.* per unit (or, in the view of the Committee which considered Sir John Snell's report, 0·844*d.* by that date). Who then could reasonably quarrel with the round figure of 1*d.* being taken as a basis of general comparison? The figure was further justified by the Report of the Weir Committee, who found that the average price of power over the United Kingdom in 1923 was 2·047*d.* per unit. When it was realized that most pumping-stations had to be placed in remote positions, it would seem that, if anything, the figure actually taken erred on the low side, in spite of the advantageous rates offered by many power-stations to customers whose load-factor was high. The matter, however, was clinched by the consideration that the generation of power at the pump crossheads of a plant such as that described was, in general, more efficient, reckoned on steam-consumption, than at the coupling of a motor driven even from a super power-station. In the calculation the power-station mean consumption was taken at 11 lbs. of steam per unit generated. Of the units generated, 10·4 per cent. was assumed to be used in station auxiliaries; of the busbar power 5 per cent. was assumed to be lost in transformation and transmission, and the

Digitized by Google

efficiency of the motor was taken at 92 per cent. This involved a steam-consumption (generally of very much higher grade steam than that required by the pumping-engine) of 10·5 lbs. per horse-power-hour, as against say 0·94 × 10·6, or 9·97 lbs. for the Lea Bridge engine at the pump crossheads. If then an electric power-station and distributing plant, which involved a very large amount of capital, used as much fuel per brake horse-power as the steam-driven pump used per crosshead horse-power, it was, in general, impossible for the former to compete in the long run. Two speakers had quoted the surprisingly low rates for high load-factor power now available in the districts surrounding the largest power-stations. The Author, however, was of opinion that such rates could hardly be taken as typical. Moreover, in fairness to the steam plant, it should be remembered that the price of coal for the purposes of Table IV was taken at £1 per ton, whereas in localities where the cheapest power was available coal of good thermal value cost little more than half that amount. But even comparing power at $\frac{3}{8}d.$ and coal at £1 per ton in a station such as Lea Bridge, the electric power would cost about $1\frac{1}{2}$ to $2\frac{1}{2}$ times as much as the coal. The Author.

He did not at all agree with Mr. Thwaites's contention that he had taken too high boiler-efficiencies. At Lea Bridge the efficiency of the steam-raising plant was 75·4 per cent., and efficiencies in large waterworks plants rarely fell below 70 per cent. Nor, as mentioned above, did he think 23*s.* a fair price for coal in districts of cheap electric power. But taking Mr. Thwaites's amended figures of combined capital and fuel costs per water horse-power-hour for steam plant, those figures referred only to examples 8, 9, 10, 11, and 12 of Table IV (p. 237). Of these Nos. 9, 10, and 12 were not of the Lea Bridge type, while No. 8, though of that type, included borehole pumps and was of comparatively small size. No. 11 was therefore the only example of the type described in the Paper, and even Mr. Thwaites's amended figure for this was only 0·34*d.* per water horse-power-hour. With regard to the electrically-driven plants, the last on the list, the only one which could compare with the above figures had a very exceptionally high lift and, though included in the comparative list as the most efficient electric water-works plant known to the Author, worked under conditions hardly comparable with those at Lea Bridge. Nevertheless Mr. Thwaites's figures undoubtedly showed that under certain circumstances electric driving could compete with certain forms of steam driving, though unlikely seriously to menace the Lea Bridge type in its own domain.

Regarding Mr. Smith's comparison of the Lea Bridge type with

Digitized by Google

The Author. an electrically-driven set of the same capacity, it should be remembered that the speed of the pumps was determined by the size of the pumps themselves, not by the driving agent. The steam-engine at Lea Bridge could easily have been made to run more quickly—and in fact would then have been both cheaper and more efficient; but the pumps, however driven, must for purposes of fair comparison be limited to their actual speed. Moreover, the power costs deduced by Mr. Smith appeared to be based on an overall (motor, gearing, and pump) efficiency of 89 per cent., which was unusually high.

With regard to the initial cost of foundations and buildings and to the additional running-costs due to extra labour, rates, and taxes, those were undoubtedly factors which militated against the steam plant as compared with electric driving. Taking current at 0·6*d.* per unit, and the overall efficiency of the electrically-driven plant at 85 per cent., he had calculated the excess which could be spent on the foundations of a plant of the size of that at Lea Bridge, so as to bring the total fuel and capital costs up to the same amount as the combined power and capital costs of the corresponding electrically-driven plant. This amount, on the assumptions of Table IV, was just less than £80,000, or, allowing also three additional shifts, each of three stokers and three cleaners at £3 a week, about £60,000, sums far exceeding the additional building costs. The above calculation did not take into account rates and taxes. Even taking the figure of 0·4*d.* per unit, the corresponding excess expenditures allowable would be about £35,000 and £15,000 respectively.

Mr. Honeysett's estimates of the number of running-hours per year necessary to justify the expense of installing a triple-expansion pumping-engine were exceedingly interesting, and the Author would like to thank him for showing up the matter in that new light.

He quite appreciated Mr. Fairley's objection to his somewhat hasty dismissal of town gas. He had never intended to suggest that town gas could not compete with electric driving.

Regarding the objection that many of the figures in Table IV were based not on actual tests but on estimated efficiencies, that was done because only in very rare cases were two plants of different types to be found working under the same conditions. It had therefore been thought better to contrast projected installations which were strictly comparable than to attempt to make all the allowances necessary to bring into accord the varying conditions of actual tested plants. In that connection it was of interest to note that the

Digitized by Google

consumption of coal of the Lea Bridge station over a period in actual working was 1·87 lb. per pump horse-power-hour. Since this included a compound engine besides the triple, it would appear that the 10 per cent. and 20 per cent. allowance was in this case ample. The Author.

Mr. Key's figures of relative costs at Alexandria of steam and Diesel pumping were of great interest. The steam-engines in this case appeared to be much less efficient than that at Lea Bridge, while the coal appeared to be much dearer and of inferior quality. Under such conditions Diesel pumping would appear to be the more economical, though the maintenance and repair bills told their own story as to relative reliability. The constant replacements which went to swell the repairs costs of oil and high-speed steam-engine drives virtually provided a new plant as often as needed, so that, except for obsolescence, the plant would be virtually everlasting. On the other hand the heaviness of the repairs costs and the unreliability inseparable from frequent repairing had to be taken into account.

As regarded the flexibility of the Diesel engines referred to by Mr. Key, the Author was much interested in the wide range of speed obtainable, which, in a type of engine giving only one working stroke per cylinder every two revolutions, must have necessitated very ample fly-wheel effect.

Mr. Maude had suggested that a longer life than 10 years should have been taken for the high-speed machinery. Perhaps the life assumed was on the short side, but in fixing it the Author had had in mind that the plant was assumed to be running almost continuously, and also that the life was to be comparable with the figure of 25 years for the slow-running plant, which, as pointed out in the Paper, was a very conservative estimate. As to the life of the Lea Bridge type, what figures could be more striking than those given by Mr. Stilgoe, although the older examples cited were not, of course, capable of the economy demanded of modern plant?

With regard to Mr. Hider's point as to the maintenance of the efficiency of the Corliss valves, the valves in the Lea Bridge engine were made in two parts—the valve proper and the cap, the two being urged apart by suitable springs. Any wear which took place was taken up by the springs, with the result that the valves, having once made for themselves a "skin," kept permanently tight. That had been confirmed by consumption tests taken after years of work.

Digitized by Google

The Author. He had noted with much interest the suggestions of Mr. Hider and Mr. Maude for the more efficient utilization of the exhaust end of the heat-drop. As pointed out by Mr. Mawson, this was undoubtedly the most hopeful direction in which to attack the deficit between the existing and the Rankine-cycle engine. The exhaust-steam turbine especially was an attractive proposition, but it was usually necessary to steer quite clear of increased complication. The Author could not at all agree with Mr. Roger Smith that it was probably not worth while to employ a vacuum higher than 26 inches, owing to the size of low-pressure cylinder involved. Even if the steam was not expanded below, say, 18 inches of mercury, as at Lea Bridge, the work obtained owing to relief of back pressure alone was well worth the small expenditure on an efficient condenser and air-pump. At Lea Bridge it was approximately 20 per cent. of the indicated horse-power, or nearly 5 per cent. per pound of pressure-relief below release. As Mr. Smith pointed out, the possibility of easily obtaining high vacua was an intrinsic economy of the steam pumping-engine for waterworks purposes.

Turning to the other end of the heat-drop, doubt had been expressed as to whether the lower fuel-consumption was worth the troubles in the boiler-house, etc., introduced by the adoption of higher pressures. The Author was emphatically of opinion that higher pressures were the road to progress, and power-station design certainly gave the lead in this direction. The President's remarks as to the behaviour of steel at high temperatures (up to 700° F.) confirmed the Author in this opinion, since the highest temperature advocated was 700° F., which was well below the critical region to which the President had drawn attention. Lubrication also was easily practicable up to this temperature, provided it was carefully applied.

Concerning the engines at Hamburg mentioned by Mr. Cotterell, the Author would not claim that all engines using a large thermal range must have a low steam-consumption, but only that a wide range was a necessary condition for the highest efficiencies.

With regard to Mr. Cotterell's point concerning the overlapping of the combined indicator-diagrams of Fig. 3, Plate 4, this was due to inaccuracy of the indicators. The Author had corrected it in transferring to the $I\phi$ diagram, where points G and H were shown at the same pressure.

He was much interested in Mr. Hider's surmise that jacketing and reheating was excessive. He was inclined to think that Mr. Hider's doubts were very probably justified, but more experiments were required. The vacuum jacket used in some

Digitized by Google

instances by Mr. Henry Davey, M. Inst. C.E., might, under certain conditions, help towards economy. The Author.

With regard to Mr. Mawson's point as to the driving of the boiler feed-pump, the usual practice of the Author's firm was to drive this pump direct from one of the main pump crossheads, and the fuel-consumptions taken on p. 216 for the Lea Bridge type of engine mostly provided for the small extra work of driving it. In the case under review, however, the boilers and accessories were provided under a separate contract. For that reason also the Author could not comment upon the economizer efficiency.

As regarded the slip, it was true that the indicator diagrams alone would not detect leakage. They could only indicate the punctual opening and closing of the valves, without which slipless running would be impossible.

With regard to Mr. Clark's communication, the Author quite appreciated Mr. Clark's division of the efficiency into three factors. The last two of these the Author had intended to separate at the bottom of p. 222, but he was much indebted to Mr. Clark for the separate characterization of them, which he agreed might with advantage be adopted universally. To the boiler efficiency the Author feared he had not devoted much space. In this connection he realized, of course, that more fuel was necessary to evaporate the higher grades of steam, and he ought perhaps to have drawn attention to the fact on p. 224. But the percentage increase was small—in fact, almost negligible, when compared with the corresponding percentage gain in availability.

The concept of "mean effective temperature" was new to the Author, but he agreed with Mr. Clark it would often be a convenient one. The Author thought it was important in this connection to emphasize that the averaging was on an entropy basis.

He noted that Mr. Clark stated that "the efficiency of the engine would be improved by making the steam conditions worse." In the case of the triple-expansion engine working between the limits at present usual, the Author very much doubted this as far as extension towards *higher* pressures and temperatures was concerned, though he agreed in the matter of improved vacua, and he had in fact attempted to convey this converse impression by the statement on p. 224 to the effect that it was the high-pressure end of the heat-drop which was most efficiently utilized by the reciprocating engine. That was perhaps best visualized by considering what was the mechanical effect, in a given engine, of moving the "starting-point" of the steam up its adiabatic, that was, using

Digitized by Google

The Author steam slightly hotter and at a slightly higher pressure. Neglecting condensation losses, such steam could be cut off slightly earlier than before, and yet when the piston reached its former cut-off position it would have attained its former "starting-point" conditions. Up to this point its mean effective pressure would have been higher than previously and therefore the work done greater, while afterwards it would be precisely as before. Thus the engine had done further work with very little additional loss—less, at any rate, than the average loss on the whole heat-drop, since this average loss was swelled by the large "toe" loss at low-pressure release. Hence its efficiency was increased.

In conclusion, the Author, having attempted to present a fair comparison, would like to record his entire agreement with Mr. Mawson that the considerations advanced could only cover part of the field to be traversed when a choice as to the type of pumping-plant had to be made in any particular circumstances.

Digitized by Google

ANNUAL GENERAL MEETING.

11 May, 1926.

FREDERICK PALMER, C.I.E., Vice-President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the minutes of the Annual General Meeting of the 12th May, 1925, which the Chairman was authorized to sign.

The following Report of the Council (p. 269) upon the Proceedings of The Institution during the Session 1925–26 was read, the statement of Accounts (pp. 287–299) being taken as read.

After consideration, it was resolved,—That the Report of the Council be received and approved, and that it be printed in the Minutes of Proceedings.

The Scrutineers reported the election of the Council for 1926-1927, as follows[1]—

President.

FREDERICK PALMER, C.I.E.

Vice-Presidents.

Sir Archibald Denny, Bart.
Ernest Frederic Crosbie Trench, C.B.E., M.A.
Sir Brodie Haldane Henderson, K.C.M.G., C.B.
Sir John Francis Cleverton Snell, G.B.E.

Other Members of Council.

Robert Donald Thain Alexander, D.S.O., O.B.E.
Henry Newmarch Allott.
Thomas Henry Bailey.
Albert Ashley Biggs.
Sir Dugald Clerk, K.B.E., D.Sc., F.R.S.
Rookes Evelyn Bell Crompton, C.B., *Col.* R.E. (T.).
Henry Albert Cutler.
Professor William Ernest Dalby, M.A., F.R.S.
Sydney Bryan Donkin.
Sir Alexander Gibb, G.B.E., C.B.
William Wylie Grierson, C.B.E.
Sir Robert Abbott Hadfield, Bart., D.Sc., D.Met., F.R.S.
Ernest Prescot Hill.
George William Humphreys, C.B.E.

[1] The Council commence their year of office on the first Tuesday in November, 1926.

Digitized by Google

Other Members of Council—continued.

Thomas William Keele.
Sir Cyril Reginald Sutton Kirkpatrick.
Sir Murdoch MacDonald, K.C.M.G., C.B., M.P.
Sir Henry Percy Maybury, K.C.M.G., C.B.
George Taylor Nicholson.
Sir Richard Augustine Studdert Redmayne, K.C.B.
Sir Hugh Reid, Bart., C.B.E., LL.D.
Professor Robert Julian Scott.
William Archer Porter Tait.
Henry Hague Vaughan.
John Duncan Watson.
Sir Alfred Fernandez Yarrow, Bart., F.R.S.

Resolved,—That the thanks of the Meeting be given to the Scrutineers, and that the Ballot-Papers be destroyed.

Resolved,—That the thanks of The Institution be given to Messrs. P. D. Griffiths and M. F.-G. Wilson, Auditors, and that they be reappointed Auditors for the current financial year.

Mr. Wilson acknowledged the resolution.

Resolved,—That the thanks of the Meeting be accorded to Mr. Frederick Palmer, Vice-President, for his conduct of the business as Chairman of the Meeting.

The Chairman acknowledged the Resolution.

The proceedings then ended.

Digitized by Google

REPORT OF THE COUNCIL, 1925–26.

In presenting their Report on the state of The Institution, the Council are glad to note that the increase in the number of candidates seeking election to corporate membership, which they reported last year, has been more than repeated, and that the majority of the candidates were, or had previously been, Students of The Institution. Again the very large majority of the candidates coming forward show the high qualifications demanded by the by-laws. The net result for the past year is an addition of 98 to the roll of corporate members, which, having regard to the losses by death or from causes more or less accentuated by the adverse conditions of recent years in the Engineering profession, may be regarded as satisfactory. The Students have also increased in number, and the only class which shows a decrease is that of the (non-corporate) Associates. Sixty-nine Associate Members have been transferred to full membership during the year under review.

The fact that 99 per cent. of the present roll of 9,800 consists of fully-qualified corporate members, or of young men (under the age for election) who have given definite guarantees that they are being trained under conditions which will in due course qualify them to join the corporate ranks of The Institution, bears witness to the homogeneous character of its membership; and the steady growth of so large a roll under the stringent conditions of education, training, and experience, must be gratifying to all who have the welfare and progress of The Institution at heart, and are convinced of the value to the community of an efficient Engineering profession.

Examinations

The candidates sitting for the Institution examinations, at home and abroad, numbered 855, of whom 241 took the Preliminary Examination, and 614 the Associate Membership wholly or in part. The numbers show a considerable increase over last Session in the Preliminary, and a very slight decrease in the Associate Membership Examination.

As to the examinations themselves, the Council have recently decided upon some modifications in the syllabuses and requirements, which they believe will keep the tests of scientific knowledge abreast of the developments in engineering practice and will tend further to promote the acquisition of a broad general education as a preliminary to scientific studies and practical training.

One of these changes consists in making a foreign language

Digitized by Google

compulsory in the Preliminary Examination, and the removal from the Associate Membership Examination of the test in a modern foreign language, which for the last seven years has been a compulsory part of Section C for all who have not passed in such a language at the Preliminary stage. As the result of experience during that period the Council, whilst in no way departing from the view that it is in the interests of most young engineers to possess a working knowledge of at least one foreign tongue—an acquisition which not infrequently may turn the scale where an appointment on work in a foreign country is in question—have come to the conclusion that cases arise in which an absolute requirement of this kind, such as is inevitable in a rigorous examination scheme, may not always be effective in promoting the real object in view, and may even deter some candidates of suitable professional training from joining The Institution, if included in the Associate Membership Examination. On the other hand, insistence on a foreign language in the Preliminary Examination will bring that examination more closely into line with the majority of matriculation or school examinations held by general educational bodies, besides securing to candidates a good foundation for such vocational use of languages as may be called for in their subsequent careers.

Another change to be made in the Associate Membership Examination is the addition, to Section A, of a compulsory Paper in Electricity and Magnetism, the Council taking the view that the time has arrived when every engineer should be required to possess a general knowledge of the principles, construction, and working of electrical appliances and machinery. The compulsory subjects of Section A will thus become:—(1) Mechanics; (2) Strength and Elasticity of Materials; (3) Electricity and Magnetism, and (4) *either* Theory of Structures *or* Theory of Machines, the latter alternative providing for the two main categories of Structures and Machinery, into which engineering work may be broadly divided.

Further, having regard to the important developments in recent years in branches of engineering work which depend upon applications of chemical science, it has been decided to add a new subject, Applied Chemistry, to Section B of the Examination. The Paper will cover (*a*) chemistry of air, water, and sewage; (*b*) chemistry of fuel, combustion, gas-manufacture, oils, and lubricating oils; and will provide alternatives for those whose study of the subject has been specialized in different directions.

The changes referred to above will take effect from and with the April Examination, 1927, provision being made, however, for transitional regulations during a certain period.

Digitized by Google

Professional Conduct.

The Council have continued to give very close attention to the subject of professional conduct and to the administration of the by-laws regulating that matter. Comparatively few cases calling for action have arisen during the period under review; but on several occasions questions have been put before the Council which have pointed in their opinion in two cases to the desirability of their expressing publicly, for the guidance of members of The Institution, what they believe to be correct professional conduct in certain given circumstances. These pronouncements having been already circulated in the "Sessional Notices," it may suffice to say here that one of them related to the remuneration of members who act as engineers for structural work but who allow the designs to be prepared by engineers connected with and paid by the contractor, and the other to the undesirability of response to advertisements of local and other authorities inviting engineers to submit, in competition with others, their terms or fees for preparing reports, plans, etc., for or in connection with engineering work.

During the year under review several matters have arisen affecting general interests of the Engineering profession, as well as those of particular branches, and in regard to which the Council have felt it to be desirable for The Institution to be associated in deliberation and action with other societies concerned with such special interests.

Naval Engineers.

In the first place reference may be made to recent action of the Admiralty affecting the status of Naval Engineers in a manner which the Council regard as derogatory to the Engineering profession, and likely to be detrimental to the interests of the nation from the point of view of attracting to the Service the class of men now needed to perform the highly responsible duties of the Engineering branch of the Navy. In association with the Councils of other engineering societies, representations have been made to the Admiralty on this matter, and a deputation from The Institution, the Institutions of Mechanical and Electrical Engineers, and the Institution of Naval Architects, headed by Sir William Ellis, President Inst. C.E., was received by the First Lord of the Admiralty on the 14th January.

Regulations for Reinforced-Concrete Buildings.

Another matter in which joint action has been taken has been the regulations, made by the London County Council under the London County Council (General Powers) Act, 1909, governing the construction of buildings wholly or partly of reinforced concrete. In accordance with the Act, the London County Council gave notice to The Institution, the Royal Institute of British Architects, the Institution of Structural Engineers, and the Surveyors'

Digitized by Google

Institution, of its intention to apply to the Ministry of Health for allowance of certain intended revision of the regulations, and submitted particulars of its proposals. The Council felt that the most satisfactory course would be joint examination of these proposals on behalf of the four societies concerned, and a Committee consisting of two representatives of each was appointed, under the Chairmanship of Dr. Unwin. This Committee, after exhaustive study of the matter, drew up a report making important suggestions in regard to the proposed revision. Their report has been transmitted to the London County Council, and is receiving consideration.

The London County Council has since introduced a Bill in the House of Lords in which the powers to issue regulations, referred to above, are to be extended to apply to the conversion of any building or part of a building constructed wholly or partly of reinforced concrete. The Joint Committee, having considered the Bill and having drawn attention to certain objections thereto, the Council have petitioned against the Bill, with a view to the preservation and better definition of the rights of The Institution under the existing Act. Similar action has been taken by the other bodies represented on the Committee.

Legislation affecting the Engineering profession.

The growing tendency on the part of professional and semi-professional associations to seek statutory or other official recognition and regulation of the qualifications which they confer is a matter to which the Council find themselves obliged to give increasing attention, in order that the professional activities of members of The Institution may not be prejudicially affected by the delegation of wide powers to bodies concerned with matters that are more or less connected with engineering work under the conditions of practice obtaining in various parts of the Empire. The Council will be glad to have their attention drawn to matters of this kind; they will give very careful consideration to information and views put before them, and will be prepared to take action—as they have done already—in cases where intervention appears to be called for to safeguard the rights of members to practise their profession as fully qualified engineers.

Representation of The Institution on other Bodies.

The following nominations and appointments have been made or renewed by the Council during the past year, and The Institution is now represented on various advisory or administrative bodies as under—

Council of the City and Guilds of London Technical Institute	The President.
Royal Commission for Exhibition of 1851	The President.

Digitized by Google

Grant Committee of the Royal Society	The President.
Sectional Committee of British Standards in Colonial and Foreign Trade (British Engineering Standards Association)	The President.
Main Committee of the British Engineering Standards Association	Sir John Aspinall. Sir John Dewrance. Sir William H. Ellis. Mr. T. Hardie. Mr. E. P. Hill. Dr. W. C. Unwin. Mr. M. F.-G. Wilson.
Paints and Varnishes Committee, B.E.S.A.	Mr. F. E. Wentworth-Sheilds.
General Board of the National Physical Laboratory	Dr. W. C. Unwin. Mr. Basil Mott.
Governing Body of the Frank Denning Trust	Mr. A. E. Cornewall-Walker.
Nomenclature Panel, Hydraulic Turbines for Electrical Plant, B.E.S.A.	Mr. Evan Parry.
L.C.C. Tribunal of Appeal (General Powers) Act, 1909	Sir Robert Elliott-Cooper.
Advisory Panel on Transport (Ministry of Transport)	Mr. John A. Brodie. Mr. O. H. R. Bury. Col. R. E. B. Crompton. Sir John P. Griffith. Mr. J. A. Saner.
Royal Engineer Board	Sir Brodie H. Henderson.
Selection Committee for the appointment of Assistant Executive Engineers in the Indian Service of Engineers and the Indian Railway Service of Engineers	Sir Robert Elliott-Cooper.
Alloys and Iron Research Committee of the Institution of Mechanical Engineers	Sir Robert Hadfield, Bart.
British Committee of Fifth International Road Congress, Milan, 1926	Mr. John A. Brodie.
Engineering Joint Council	Sir Charles Morgan. Mr. Basil Mott.
St. Paul's Cathedral Preservation Committee	Sir Charles Morgan.

Digitized by Google

British Cast Iron Research Association	Sir Robert Hadfield, Bart.
British National Committee of the World Power Conference	Sir Charles Morgan. Sir Dugald Clerk.
Jubilee Meeting of the Royal Sanitary Institute	Mr. G. W. Humphreys. Mr. J. D. Watson.
Agricultural Engineering Committee of the University of Oxford	Sir John Wormald.
Court of the University of Bristol	Mr. W. W. Grierson.
Court of the University of Liverpool	Mr. John A. Brodie.
Court of Governors of the University of Sheffield	Sir William H. Ellis.
University College, Southampton	Mr. F. E. Wentworth-Sheilds. Mr. W. J. Taylor.
Governing Body of the School of Metalliferous Mining (Cornwall)	Mr. J. G. Lawn.
Governing Body of the Imperial College of Science and Technology	Dr. W. C. Unwin.

No. 1 Great George Street.

Reference should be made to the premises No. 1, Great George Street—the lease of which expired at Midsummer, 1925. The original intention was that the house should then be demolished and the Institution building be completed, part of the site being, by agreement, handed over to the City of Westminster, to enable Princes Street to be widened at that corner at a later date. Having regard, however, to the prevailing financial conditions, the Institution Council approached H.M. Office of Works on the question of permitting the premises to remain standing for a further period. They are glad to be able to state that an arrangement has been come to on terms, and that the house has been let on lease for seven years.

Heat Engine Trials Committee.

In mentioning the progress of the work of the Heat Engine Trials Committee, the Council wish first to refer to the heavy loss which that Committee has sustained by the death of Captain H. Riall Sankey, its Chairman. Captain Sankey was Chairman of the original Steam-Engine and Boiler Trials Committee appointed by The Institution in 1907, and before that he was Secretary of the Institution Committee on the Thermal Efficiency of Steam-Engines. Indeed, his profound knowledge and wide experience of this branch of engineering have been constantly and freely placed at the service of The Institution since the days when he collaborated with Mr. P. W. Willans in his well-known researches and writings, about 35 years ago.

Mr. W. H. Patchell, M. Inst. C.E., has been appointed to succeed Captain Sankey as Chairman of the Committee.

Digitized by Google

During the year the Committee have continued the preparation of codes for tabulating the results of steam-generating plant and heat-engine trials. They have decided to include also a code for tabulating the results of air-compressor trials. It is hoped to issue towards the end of May a draft of the Committee's final Report. This draft will be given wide publicity, and comments and suggestions will be invited in order that all points of view may be considered before the final Report is issued. The Institution of Automobile Engineers and the Incorporated Municipal Electrical Association have recently accepted invitations to nominate representatives upon the Committee.

Sea-Action Committee.

The work of the Committee on the Deterioration of Structures Exposed to Sea-Action, commenced in 1916, is still in progress.

The usual half-yearly reports on the various steel and iron specimens exposed at Auckland, Colombo, Halifax and Plymouth have been received. Three series of these specimens were exposed, the first series to be taken up for examination after 5 years, the second after 10 years, and the third after 15 years' exposure. In the cases of Auckland and Halifax, the first of these will have been exposed for 5 years by the coming summer, and will be taken up and returned to England for examination by Dr. Friend, who has been advising the Committee with regard to these investigations.

During the past 18 months steel specimens coated with different surface preservatives have been exposed at Southampton Docks under the supervision of Mr. F. E. Wentworth-Sheilds. These specimens were subjected to exposure in positions where they would be—

(*a*) totally immersed during all stages of the tide;
(*b*) at half-tide level, or
(*c*) exposed to sea air.

Series (*a*) and (*b*) have been taken up for examination by Dr. Friend, and measurements have been made as to loss of weight and pitting. The aerial specimens (*c*) having shown much greater resistance than those submerged, have been allowed to remain for further exposure until such time as their deterioration indicates that it is advisable to remove them also for examination. The results of the examination of the plates subjected to complete and half-tide immersion have been fully reported on by Dr. Friend to the Committee, and will be published in due course. They show, so far as a limited number of experiments can do so, an appreciable superiority of bituminous and tar coatings over paints and other preservatives. As these experiments appear promising, further investigations are being made to confirm the results of those already recorded and to deal with other preservatives.

Digitized by Google

The experiments on timber impregnated with poisons are still in progress, and a large number of additional specimens impregnated with different protective substances have been sent to Colombo and Singapore for exposure in order to test the effects of those poisons which have appeared to be the most efficacious in different waters. The specimens of poisoned timbers exposed at Lowestoft have all, with one or two exceptions, been removed, and the Committee hope in their next interim report to publish the results and information obtained therefrom.

The mechanical tests on a considerable variety of foreign timbers, referred to in the last report as being carried out by Professor Dixon at the City and Guilds (Engineering) College, have now been completed, and a most interesting report thereon has been submitted to the Committee. An abstract of this report will be published in the next interim report.

The Committee's sixth (interim) Report is now in the press and will be published in the course of a few months' time.

During the coming year it is hoped to carry out some experiments on the impermeability of concrete to sea air, which will supplement an investigation that has recently been carried out under the auspices of the Department of Scientific and Industrial Research, on its impermeability to water, experiments having indicated that the deterioration of reinforced-concrete structures is most rapid where the concrete is exposed not to sea-water alone but to the action of sea-water and air.

Yarrow Scholarships.

Yarrow Scholarships, tenable for 2 and 3 years respectively, have been awarded to John Britton Murray and James Stewart Robertson, to enable these scholars to complete their engineering training.

Lindley Scholarship.

It is understood that the executors of the late Mr. R. S. Lindley, M. Inst. C.E., contemplate adding to the endowment fund a sum which will double the original annual value of the William Lindley scholarship, namely £40. This scholarship, which is open to sons of corporate members of The Institution, is at present vacant.

Coopers Hill War Memorial Prize.

Two essays have been received in competition for the Coopers Hill War Memorial Prize in 1925, and the Council have awarded the Prize (which consists of a bronze medal, a certificate, and the sum of about £30) to Mr. E. L. Everatt, Assoc. M. Inst. C.E., for his essay on "Maintenance Dredging in Bombay Harbour and Docks, and Upkeep of the Navigational Lighting of the Port." This essay will in due course be published as a "Selected Engineering Paper."

Subjects for the competition for 1926 have been announced recently in the "Sessional Notices"; and the Council trust that this year a larger number of essays will be submitted for the award.

Digitized by Google

The Annual Dinner, at which The Institution was honoured by the presence of H.R.H. the Prince of Wales, K.G., Honorary Member, was held in the Great Hall of the Institution on Wednesday, the 10th March, and was attended by 297 members and guests. The Council felt that the remarks made by His Royal Highness, in acknowledging the Toast of "His Royal Highness the Prince of Wales and the Other Members of the Royal Family," and proposing that of "The Institution of Civil Engineers," would be gratifying to all members and students of The Institution, and therefore caused a report of the Prince's speech to be issued in the March number of the "Sessional Notices." Annual Dinner.

The annual Conversazione will take place at the Institution on the 16th June. Conversazione.

The Roll.

The Roll of The Institution on the 31st March, 1926, stood at 9,774, the changes which took place in it during the year ended on that date being shown in the following Table :— Enumeration.

	1 April, 1924, to 31 March, 1925.						1 April, 1925, to 31 March, 1926.					
	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.
Numbers at commencement	17	2302	5800	108	1275	9502	16	2301	5837	91	1398	9643
Transferred to Members	..	67	67	..	..		..	77	77	..	..	
Elections	3	24	236	1	..		1	20	254	1	..	
Admissions	..	..	..	..	353	639	..	..	..	..	332	632
Restored to Register	..	1	19	..	2		..	3	16	..	5	
Deceased	4	62	47	14	1		1	61	46	5	4	
Resigned	..	20	55	3	18		..	19	38	3	17	
Erased	..	10	49	1	13		..	3	27	2	4	
Elected to Honorary Member	..	1	..	..	..		..	..	..	..	..	
Elected to Associate Members	..	..	..	..	37	198	..	..	..	..	60	501
Removed—over age	..	..	..	..	160		..	..	..	..	198	
Failed to comply (Studentship)	..	..	..	..	3		..	..	..	..	13	
						+141						+131
Numbers at termination	16	2301	5837	91	1399	9643	16	2318	5919	82	1439	9774

The Roll is, at this date, 9,809.

Digitized by Google

The Council record with especial regret the deaths of Viscount Milner, K.G., G.C.B., G.C.M.G., P.C., Honorary Member, Captain H. Riall Sankey, C.B., C.B.E., *R.E.* (*ret.*), Member of Council, Henry Norlande Ruttan, Sir Bradford Leslie, K.C.I.E., Professor William H. Warren, LL.D., and Sir Philip Watts, K.C.B., LL.D., F.R.S., former Members of Council.

General the Right Hon. Ian Christiaan Smuts, P.C., C.H., has been elected an Honorary Member, and there have also been elected 20 Members, 254 Associate Members, and 1 Associate; 332 candidates were admitted as Students, and the names of 3 Members, 16 Associate Members, and 5 Students were restored to the Register. From this addition of 632 must be deducted the deaths, resignations, and erasures during the year, the Students elected Associate Members, and those who, having passed the age-limit of the Student class, ceased to be connected with The Institution, amounting to 501 in all, showing a net addition of 131.

Deaths. The full list of deaths is as follows (E *refers to election, and* T *to transfer*)—

Honorary Member (1).—*Viscount* Milner, K.G., G.C.B., G.C.M.G., P.C. (*E.* 1907).

Members (61).—Wilfrid Airy, B.A. (*E.* 1867. *T.* 1874); David Angus (*E.* 1882. *T.* 1893); Frederick William Bach (*E.* 1887. *T.* 1907); James Patten Barber (*E.* 1893. *T.* 1894); Sydney Walter Barnaby (*E.* 1881. *T.* 1888); John Frederick Evelyn Barnes, C.M.G. (*E.* 1886. *T.* 1889); Arthur Henry Bastow, M.A., M.C.E. (*E.* 1900. *T.* 1909); Leonard Moore Bell (*E.* 1895. *T.* 1902); Ernest Benedict (*E.* 1871); Hubert Bewlay (*E.* 1882. *T.* 1901); James Samuel Brown (*E.* 1879. *T.* 1890); William Frederic Butler (*E.* 1874. *T.* 1904); *Professor* William Robert Butler, M.E. (*E.* 1888. *T.* 1898); *Professor* David Sing Capper, M.A. (*E.* 1890. *T.* 1898); Edward Brotherton Carroll (*E.* 1869. *T.* 1877); William Dyce Cay, F.R.S.E. (*E.* 1864. *T.* 1872); Robert Hearn Charters (*E.* 1892. *T.* 1903); Henry Slade Childe (*E.* 1887. *T.* 1896); Robert Crawford (*E.* 1888. *T.* 1893); Frederick James Cribb (*E.* 1920); Edward Baudouin Ellice-Clark (*E.* 1874 *T.* 1882); Charles Alexander Falconer (*E.* 1908. *T.* 1921); Henry Algernon Shrapnel Fenner (*E.* 1868. *T.* 1877); Joseph Garfield (*E.* 1897. *T.* 1913); Charles Frederic Gettings (*E.* 1915); *Lt.-Col.* Cecil Quixano Henriques, *R.E. Vols.* (*ret.*) (*E.* 1881. *T.* 1906); Maurice Walter Henty (*E.* 1902. *T.* 1911); James Holden (*E.* 1882. *T.* 1887); Heber William Henry Howell (*E.* 1896. *T.* 1908); James Rossiter Hoyle (*E.* 1897); Henry Holmes Jellett, B.A.I. (*E.* 1893. *T.* 1900); William Pierson Judson (*E.* 1891); Frederick Washington Lawson, D.S.O. (*E.* 1909. *T.* 1914); William Henry Le Quesne (*E.* 1896); *Sir* Bradford Leslie, K.C.I.E. (*former Member of Council*) (*E.* 1872); Robert Searles Lindley (*E.* 1881); Philip Glynn Messent, C.I.E. (*E.* 1888 *T.* 1896); Cathcart William Methven, F.R.S.E. (*E.* 1875. *T.* 1882); Reginald Empson Middleton (*E.* 1870. *T.* 1885); Henry Morley (*E.* 1897); Charles Croasdaile Ormsby (*E.* 1904); Philip Henry Palmer (*E.* 1884. *T.* 1897); George Bernard Reynolds (*E.* 1879. *T.* 1892); Martin Fenn Roberts (*E.* 1884.

Digitized by Google

T. 1899); James Wilmot Andreas Rose (E. 1886. T. 1907); Harold Simeon Rowe, B.Sc. (E. 1910. T. 1922); Walter Rowley (E. 1884); Henry Norlande Ruttan (*former Member of Council*) (E. 1888); John Sampson (E. 1888. T. 1893); *Captain* Matthew Henry Phineas Riall Sankey, C.B., C.B.E., *R.E. (ret.)* (*Member of Council*), (E. 1895); Augustus Oswald Schenk (E. 1885); Emilio Armando Henrique Schnoor (E. 1896); William Sewell (E. 1878. T. 1896); John William Sowarsby (E. 1904); Edward Brownfield Wain (E. 1891. T. 1895); Harry Smith Wainwright (E. 1897. T. 1904); *Professor* William Henry Warren, LL.D. (*former Member of Council*) (E. 1877. T. 1887); Alexander James William Watkins (E. 1889. T. 1896); *Sir* Philip Watts, K.C.B., LL.D., F.R.S. (*former Member of Council*) (E. 1901); Albert Edward Welbourn (E. 1915); William Henry White (E. 1872. T. 1879).

Associate Members (46).—Edgar William Beckingsale (E. 1872); Claude Tinne Berthon (E. 1902); William Henry Beswick (E. 1888); John Robert Billington (E. 1909); George Macartney Campbell Black (E. 1894); Arthur Bowes (E. 1891); George Henry Carmichael (E. 1894); Nathaniel Chalmers (E. 1894); Henry Francis Collins (E. 1891); William Thomas Curry (E. 1888); David Davies (E. 1891); David Inglis Dawbarn, M.Eng. (E. 1924); William Eugene Desbruslais (E. 1910); Robert Henry Burnside Downes (E. 1887); Giulio Festa (E. 1891); Joseph Fisher (E. 1915); George Edward Fleming (E. 1894); Stafford Gaffney, M.A.I. (E. 1896); John Berridge Gaskell (E. 1892); William Graham, B.Sc. (E. 1912); Patrick Campbell Hart (E. 1894); Arthur Henry Heath (E. 1873); Charles Graham Hepburn (E. 1902); Walter Hewson, B.Sc. (E. 1904); James Cadoux Hudson (E. 1879); Charles Frank Hunt (E. 1909); Harry Birch Killon (E. 1893); George Potter Knowles, M.B.E., B.Sc. (E. 1905); John William Logan (E. 1880); Frederick Charles Lynde (E. 1885); Frederick William Moon, B.E. (E. 1900); John Macintosh Mackay Munro (E. 1894); George Douglas Alfred Myers (E. 1905); Udham Singh Nakai (E. 1919); Lenox Napier (E. 1913); Godfrey Bernard Parlett (E. 1892); Thomas Pope (E. 1892); Fergus William Slane (E. 1915); Henry Lewis Spindler (E. 1877); Andrew Stenhouse (E. 1915); Alfred Tomlinson, M.Sc. (E. 1910); Herbert Unwin (E. 1870); William Carlile Wallace (E. 1895); William Warren (E. 1885); Walter Lionel Wilkinson (E. 1906); John Woodside (E. 1889).

Associates (5).—William George Cooke (E. 1899); Edward Herbert Davies (E. 1908); Thomas Tyson Middleton (E. 1908); *Sir* David Lionel Salomons, Bart. (E. 1882); Edward Percy Simpson, M.A. (E. 1897).

Students (4) (*A. refers to Admission*).—Herbert Bruce Fulford, B.Sc. (A. 1925); Leonard Rudolph Marsden (A. 1922); Alfred James Marshall (A. 1923); Eric William Schlanbusch (A. 1923).

The following resignations have been received— Resignations

Members (19).—Ernest Edmund Brydone-Jack (E. 1914); Arthur de Courcy Carson (E. 1916); William Collen, M.A., B.A.I. (E. 1894. T. 1898); Frederick John Dick (E. 1888. T. 1898); Harry Francis (E. 1884. T. 1901); Albert Gordon, M.A.I. (*former Member of Council*) (E. 1884); William Kaye-Parry, M.A., B.A.I. (E. 1894. T. 1899); Charles Anthony Kirby (E. 1892); William Henry Ledger, M.C.E. (E. 1918); Richard William Frederick Longfield, B.A.I. (E. 1894. T. 1902); John Storan Molony, B.A., M.E. (E. 1883. T. 1908); Edward Raymond Peal, C.B.E., D.S.C.

Digitized by Google

(*subsequently reinstated*) (E. 1910. T. 1921); Hastings FitzEdward Peet (E. 1904. T. 1905); William Brailey Richards (E. 1914); Walter Saise, D.Sc. (E. 1887). Frederick Orlando Stephens (E. 1886. T. 1903); *Maj.-General Sir* Andrew Mitchell, K.C.M.G., C.B., *R.E.* (*ret.*) (E. 1921); Harry Howard Webb (E. 1901); Alfred George White (E. 1884. T. 1899).

Associate Members (38).—*Professor* Edgar Alfred Allcutt, M.Sc. (E. 1914); Matthew Edmund Moore Anderson, B.A. (E. 1907); Percy Vavasseur Appleby (E. 1890); Ediss Lancelot Bascombe (E. 1912); George Arthur Becks (E. 1891); Edward Leigh Bennett (E. 1900); Eric Carus-Wilson, M.C., B.A., B.Sc. (E. 1917); William Ranson Cooper, M.A., B.Sc. (E. 1900), Ralph Henry Covernton, M.C. (E. 1897); Edward Wortley Dale, B.E. (E. 1911); James Gray Docherty, B.Sc. (E. 1921); Francis Bragg Drake (E. 1895); Bertram William English (E. 1892); Henry Elliot FitzGibbon, B.A., B.A.I. (E. 1920); Maurice Graham, C.B.E. (E. 1893); Edward Long Grove (E. 1899); William Henry James, M.Sc. (E. 1900); Pedro Ricordo Jordi, B.A.I. (E. 1914); Christopher Rowley Hill Kane (E. 1920); Walter Robert Kay (E. 1898); Andrew Kilgour (E. 1917); Leslie Duncan Macgeorge (E. 1883); Eric McGregor, M.C. (E. 1917); Joseph Ernest Martin (E. 1887); Matthew Sinclair Mayne, B.Sc. (E. 1920); Drogo Montagu (E. 1896); Arthur Mudd (E. 1912); Edward Leslie Robert Muir (E. 1889); Alexander Roderick Murray (E. 1910); Robert Frederic Nathan, B.A. (E. 1920); Frederick Dossey Phillips (E. 1917); Ernest Lancelot Pledger (E. 1910); Howard Melville Rootham, B.Sc. (E. 1906); John Benjamin Travers Solly (E. 1905); William Henry Stanley (E. 1890); William Henry Tozer (E. 1904); John Maurice Simeon Woore, B.E. (E. 1899); Christopher Gordon Wright (E. 1904).

Associates (3).—Ebenezer Antony Lees, O.B.E. (E. 1908); Kumar Nur Singh Rana, *Bahadur* (E. 1899); Thomas William Ridley (E. 1899).

Students (17).—Richard Godfrey Arthur Colley (A. 1923); Ernest Stewart Cox (A. 1920); Frederick Charles de Segundo (A. 1921); John Arthur Duval (A. 1922); James Fairclough (A. 1920); Thomas Stanley Hake (A. 1924); Charles William Hewlett, B.Sc. (A. 1925); William Kendrick (A. 1922); Leslie Samuel Kingston (A. 1921); Harold Lionel Lidington (A. 1920); Antony Macnaghten, B.A. (A. 1923); Terence Walter Mansergh, B.A. (A. 1923); John Norman Milne (A. 1921); Harold Chilvers Sharpe (A. 1921); Charles Holbert Tole (A. 1924); Francis Thomas Wreford (A. 1920); Eric Ian Carew Wyllie (A. 1923).

FINANCE.

The following is a statement of receipts and payment for the year ended 31st March, 1926, the account of which has been duly audited. The corresponding amounts for the financial year 1924-25 are given in brackets.

The Receipts were:—On General Income Account, £41,350 13*s.* 0*d.* (*£41,349 2s. 10d.*), of which £37,082 4*s.* 9*d.* (*£36,854 5s. 8d.*) represents subscriptions and fees apportioned to the Financial Year, £1,280 7*s.* 5*d* (*£1,133 3s. 7d.*) Dividends, Interests on Investments, etc., and £162 10*s.* 0*d.* (*£650*) rent of No. 1, Great George Street.

Digitized by Google

The Expenditure was :—On General Account £39,409 4*s.* 11*d.* (*£38,632 5s. 8d.*), which included Publications £8,363 6*s.* 6*d.* (*£9,210 10s. 11d.*) and Interest on Loan under amortisation £825 14*s.* 10*d.* (*£876 14s. 4d.*).

There was received on Capital Account £2,724 15*s.* 0*d.* (*£2,714 10s. 0d.*) in Admission Fees and a Life Composition, and £1,100 16*s.* 5*d.* (*£1,055 18s. 11d.*) was applied to the extinguishment of the Loan.

On Trust Funds Income Account there was received a total of £1,397 17*s.* 10*d.* (*£1,382 5s. 7d.*), and the Expenditure amounted to £969 18*s.* 8*d.* (*£912 2s. 9d.*).

A grant of £260 (*£675*) was received from the Department of Scientific and Industrial Research on account of the investigation into the Deterioration of Structures exposed to Sea-Action, and contributions amounting to £734 15*s.* 0*d.* (*£873 5s. 0d.*) were received from Home and Colonial Harbour and Dock Authorities towards the cost of the research. The expenditure during the year was £1,409 5*s.* 2*d.* (*£1,135 8s. 3d.*).

The Sessional Meetings.

During the Session twelve Ordinary Meetings have been held, at which twelve Papers have been considered, the President's Address occupying, as usual, the opening Meeting. Under the arrangement inaugurated last Session, whereby only an abstract of each Paper is now read, no occasion has arisen to adjourn a discussion. The variety of the subjects dealt with will be indicated by the following list of titles of the Papers :—

Author.	Title.
Professor W. E. Dalby, M.A., B.Sc., F.R.S., M. Inst. C.E.	The Mechanical Properties of Steel.
H. A. Reed, M. Inst. C.E.	Trafford Wharf Reconstruction at the Manchester Docks.
A. Honeysett, Assoc. M. Inst. C.E.	Pressure-Boosting Station for the Waterworks of the City of Monte Video.
C. F. Bengough, M. Inst. C.E.	High-Level Bridge, Newcastle-upon-Tyne : Underpinning and Repair of Foundations of River Piers.
A. S. Angwin, D.S.O., M.C., B.Sc., and T. Walmsley, B.Sc., Assoc. MM. Inst. C.E.	Rugby Radio Station.

Digitized by Google

Author.	Title.
P. W. Bertlin, Assoc. M. Inst. C.E.	Construction of the New Entrance to Tranmere Dock.
V. Bayley, C.I.E., M. Inst. C.E.	The Khyber Railway.
Colonel G. R. Hearn, C.I.E., D.S.O., R.E., Assoc. Inst. C.E.	The Survey and Construction of the Khyber Railway.
O. L. Prowde, B.A., M. Inst. C.E.	The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile.
A. E. Tuffley, Assoc. M. Inst. C.E.	The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland.
J. N. Reeson, M. Inst. C.E.	The Influence of Electric Welding in the Design and Fabrication of Plant and Structures.
H. R. Lupton, M.A., Assoc. M. Inst. C.E.	The Triple-Expansion Steam-Engine as applied to the Pumping of Water, with Special Reference to the Plant at Lea Bridge.

Awards. The Council have expressed their thanks to Professor Dalby, who is ineligible to receive an award for his Paper, and have made awards for some of the other Communications considered at Ordinary Meetings to Messrs. Prowde, Lupton, Angwin and Walmsley, Bayley, Bengough, Honeysett, Reeson, Hearn, and Reed.

Informal Meetings. Six informal meetings have been held, and the Council have noted with much satisfaction a marked increase in the attendance at these meetings and in the interest taken in the discussions. As these gatherings are intended to benefit particularly the younger members, the Council have decided that the Chairman of the Association of London Students shall be ex-officio a member of the Informal Meetings Committee.

The subjects considered at these meetings were the following—

Subject.	Introduced by
The Relative Economy of Different Classes of Concrete for Reinforced-Concrete Work.	Sir E. Owen Williams, K.B.E., B.Sc., M. Inst. C.E.
The Use of Explosives for Scouring Purposes in Tidal Rivers.	C. H. J. Clayton, M.B.E., M. Inst. C.E.

Digitized by Google

Subject.	Introduced by
The Testing and Examination of Materials for Railway Construction.	F. J. Paice, Assoc. M. Inst. C.E.
British Railway Permanent-Way Maintenance.	W. A. Willox, Assoc. M. Inst. C.E.
Road Construction.	H. E. Lightfoot, Assoc. M. Inst. C.E.
The Young Engineer: his Training and Prospects.	G. W. Tripp, Assoc. M. Inst. C.E.

Publications.

In touching upon the subject of Publications, the Council desire to emphasize the fact that the first purpose of The Institution is to advance engineering knowledge. It is therefore incumbent upon every member to lose no opportunity of making original communications to The Institution which may enable it to fulfil that object.

In addition to original matter, however, the Council regard as an important feature of The Institution's activities in this respect the publication of a record of contemporary communications to engineering societies and periodicals in other countries, which has been accomplished during the past half-century by the preparation of the Engineering Abstracts formerly included in the "Minutes of Proceedings" and in recent years issued in separate form. The achievement of this aim in a manner worthy of the other publications of The Institution, and consistent with its broad constitution and membership, is naturally attended with considerable cost; and while the Council consider the necessary expenditure in this matter to be rightly incurred, from the point of view of The Institution's function emphasized above, they have been concerned to find that comparatively few members are sufficiently interested to contribute the modest sum of ten shillings per annum for the Abstracts, which merely covers the cost of presswork, paper and postage of the four quarterly numbers. They have caused attention to be drawn to the situation in the "Sessional Notices," and they trust that the result will show that greater advantage is being taken of this publication.

During the last three years exhaustive consideration has been given to the feasibility of producing such abstracts on a co-operative basis, with a view to economy and avoidance of overlapping; but

Digitized by Google

no solution of this problem has been found which would recognize the pioneer work and representative character of The Institution, and afford to its own members the advantages they can now enjoy, with material diminution of the charges at present borne by The Institution as a body. In these circumstances the Council decided to invite the co-operation of other engineering societies in the British Empire, by offering to each the opportunity of taking a certain number of copies annually at a subscription rate of fifteen shillings, leaving to the society the option of passing the whole amount on to its members or of bearing any part of it, up to five shillings, as a general charge upon the society's funds. At the same time, societies accepting the proposal were invited to nominate a member or members of an Advisory Panel set up by the Council to assist the Publication Committee in maintaining a high standard in regard to the articles chosen for notice. Whilst the response to this invitation shows that in some other societies appreciation of the value of such records of foreign engineering work is less than in the case of The Institution, the Council have received with much pleasure the assent of the Institution of Naval Architects, the Institution of Gas Engineers, the Institution of Water Engineers, and the Institution of Engineers, Australia, and they desire to express their appreciation of the co-operation of those societies in the matter.

The Advisory Panel in question is at present constituted as follows—

Appointed by The Institution of Civil Engineers.—Sir Archibald Denny, Bart., Colonel R. E. B. Crompton, C.B., R.E. (T.), Professor W. E. Dalby, M.A., B.Sc., F.R.S., Sir Alexander Gibb, G.B.E., C.B., E. P. Hill, Sir Murdoch MacDonald, K.C.M.G., C.B., M.P., Sir Richard A. S. Redmayne, K.C.B., M.Sc., Sir John F. C. Snell, G.B.E., and W. B. Worthington, D.Sc.

Appointed by The Institution of Naval Architects.—J. Hamilton Gibson, O.B.E., M.Eng., and W. J. Luke, C.B.E.

Appointed by The Institution of Gas Engineers.—Thomas Hardie.

Appointed by The Institution of Water Engineers.—William Matthews.

Appointed by The Institution of Engineers, Australia.—(Not yet nominated.[1])

In addition, the Council have invited the assistance of several other distinguished engineers and scientists as honorary referees, in order to ensure rigid and complete scrutiny of matter dealing with

[1] Mr. H. J. Deane, B.E., has been nominated since the date of this report.—SEC. INST., C.E., Dec., 1926.

Digitized by Google

some recent specialized developments of engineering work and with scientific work bearing upon professional practice. It may be desirable to emphasize here the fact that "Engineering Abstracts" is a selective publication. Of the vast volume of current engineering literature, only a portion calls for even such condensed notice and record; and the Council are satisfied that the main source of true economy lies in the exercise of the utmost care in the choice of matter in respect of which printing and circulation costs are incurred. They believe that the steps they have taken will conduce still further to the successful accomplishment of the purposes of this publication, and they tender the thanks of The Institution to the following gentlemen who, up to the present, have agreed to act as Honorary Referees for the Abstracts:—Llewellyn B. Atkinson, Professor H. C. H. Carpenter, M.A., Ph.D., F.R.S., W. H. Eccles, D.Sc., F.R.S., Oscar Faber, O.B.E., D.Sc., Sir Henry Fowler, K.B.E., J. Newton Friend, D.Sc., Ph.D., Sir Richard T. Glazebrook, K.C.B., M.A., D.Sc., F.R.S., F. W. Lanchester, LL.D., F.R.S., Thomas E. Stanton, C.B.E., D.Sc., F.R.S., James Swinburne, F.R.S., Maurice E. Unwin.

Local Associations.

The Local Associations Committee, to the formation of which reference was made in the last Report, has proved to be a valuable organization for the discussion, between representatives of the Council and of the Committees of Local Associations, of matters affecting the interests and working of the latter. One change which has been agreed upon as desirable, and has been carried out, is the alteration of the designations of "President," "Vice-President," and "Council" of a Local Association to "Chairman," "Vice-Chairman," and "Committee."

Students' Meetings and Visits.

The London Students have had a successful Session. There has been no lack of Papers for discussion, and the attendances at the nine Meetings and at the eight Visits to engineering works have shown marked improvement. Towards this result the energetic and zealous work of the officers of the Association of London Students—not only those of the present Session but also those who in the years immediately following the war were faced with still more difficult conditions—has contributed in no small degree.

Digitized by Google

Lectures.

The Vernon-Harcourt Lecture, on the subject of "The Development of Harbour and Dock Engineering," was delivered by Sir Cyril R. S. Kirkpatrick, M. Inst. C.E., in London on the 16th December. It was repeated before Local Associations at Birmingham, Bristol and Cardiff, Glasgow, Manchester, Newcastle, and Sheffield. The Lecture will be printed in due course.

The Thirty-second James Forrest Lecture is to be delivered by Senator G. Marconi, G.C.V.O., Honorary Member, on Tuesday, the 18th May,[1] the subject being "Radio Communications."

The Library.

During the year 329 volumes were presented and 191 purchased, making a total, on the 31st March, 1926, of 52,651.

Recent donations include the following:—A copy of the second edition of "An Account of Sir Isaac Newton's Philosophical Discoveries," by Colin Maclaurin, 1750, from Mr. Henry Adams, M. Inst. C.E., and an Album of photographs of the Sennar Dam and Gezira Irrigation Works, from Sir Frederick Hopkinson, K.B.E., M. Inst. C.E.

To the collection of paintings has been added a portrait of Mr. Basil Mott, C.B., Past-President, presented by himself and painted by Stanhope Forbes, R.A.

Mr. R. E. Trevithick, Assoc. M. Inst. C.E., has presented a coloured reproduction of a drawing of Richard Trevithick's Railroad, Euston Square, 1809, by T. Rowlandson; Mr. G. E. Lillie, M. Inst. C.E., a pencil drawing of the late Mr. J. R. Bell, M. Inst. C.E.; Mr. W. N. McClean, M.A., Assoc. M. Inst. C.E., a coloured reproduction of the Institution's portrait of J. R. McClean, M.P., Past-President, and Messrs. Sir John Jackson, Ltd., six engraved portraits of eminent engineers of the nineteenth century.

---

[1] The Lecture was postponed to the 26th October (see p. 303 *post*)—Sec. Inst., C.E.

Digitized by Google

APPENDIX I.

ACCOUNTS AND BALANCE SHEET, INCLUDING TRUST FUNDS.

31ST MARCH, 1926.

Digitized by Google

APPEN

BALANCE SHEET

	£ s. d.	£ s. d.
To Institution Capital Account and Building Fund, *as detailed on pages 290 & 291* . .	..	360,190 4 2
„ Loan on security of Institution Buildings. .	..	19,384 3 2
„ Creditors and Credit Balances (*including £1,457 4s. 10d. Repairs and Renewals Reserve*)	..	2,237 11 6
„ Sea Action Committee Account	..	317 6 1
„ Trust Funds, Capital and Income Accounts—		
Capital Accounts—*as detailed on page 294, invested per contra*	36,953 16 0	
Income Accounts—Balances unexpended—*as detailed on page 297*	4,475 5 10	
		41,429 1 10
„ Institution Revenue in Suspense—		
Proportion of 1926 Subscriptions applicable to the nine months from 1st April to 31st December, 1926	17,203 16 0	
Subscriptions received in advance . . .	48 12 6	
		17,252 8 6
		£440,810 15 3

AUDITORS'

We have audited the above Balance Sheet dated 31st March, 1926, and have obtained is properly drawn up so as to exhibit a true and correct view of the state of The Institution's shown by the books of The Institution.

London, 26th April, 1926.

Digitized by Google

DIX I.

31st MARCH, 1926.

	£	s.	d.
By Expenditure on Institution Buildings, including Cost of Site, *as per last account*	352,072	7	2
„ Institution Investments at cost, *as detailed on page 294* . .	28,908	2	5
Note.—*The value of these Investments at ruling prices on 31st March, 1926, amounted approximately to £22,520*			
„ Trust Funds Investments, etc.—			
Capital :—			
Investments, *as detailed on page 295* £36,953 16 0			
Unexpended Income :—			
Investments, *as detailed on page 295* £2,909 11 11			
Cash at Bank—			
On Deposit a/c 1,400 0 0			
„ Current a/c 165 13 11			
1,565 13 11			
4,475 5 10			
	41,429	1	10
„ Sundry Debtors	437	16	9
„ Cash at Bankers, and in Hand—			
At Bank—Deposit and Current Accounts :—			
Institution Funds 17,416 9 8			
Sea Action Committee Account . . 317 6 1			
17,733 15 9			
In Hand 229 11 4			
	17,963	7	1
Note.—*No value has been attached, for the purpose of this Balance Sheet, to the Books, Furniture, Pictures, Sculpture, etc., belonging to The Institution.*			
	£440,810	15	3

H. H. Jeffcott, *Secretary.*

REPORT.

all the information and explanations we have required. In our opinion such Balance Sheet affairs according to the best of our information and the explanations given to us, and as

Percival D. Griffiths, F.C.A.
Maurice F.-G. Wilson. } Auditors.

Digitized by Google

INSTITUTION CAPITAL ACCOUNT

	£	s.	d.
To BALANCE *carried down*	360,190	4	2
	£360,190	4	2

Digitized by Google

AND BUILDING FUND, 31st MARCH, 1926.

	£	s.	d.
By Institution Capital Account and Building Fund, *as per last account*	355,524	1	1
„ Receipts during the Year to 31st March, 1926—			
Admission Fees £2,698 10 0			
Life Compositions 26 5 0			
	2,724	15	0
„ Institution Revenue Account—			
Excess of Income over Expenditure for the year ended 31st March, 1926, *page 292*	1,941	8	1
	£360,190	4	2

By Balance *brought down—as per Balance Sheet, page 288* . . £360,190 4 2

Digitized by Google

INSTITUTION REVENUE ACCOUNT

EXPENDITURE.

	£ s. d.	£ s. d.
To House and Establishment Charges—		
Rates, Taxes and Insurance	5,913 12 9	
Electric Lighting and Power, Water-Supply, Warming, Ventilating and Telephone	810 1 8	
Cleaning and Household Expenses	1,320 7 11	
Refreshments and Assistance at Meetings	161 12 4	
		8,205 14 8
,, Repairs and Renewals to Structure, Furniture, Fittings and Machinery (*Expenditure, £678 10s. 11d. Provision, £321 9s. 1d.*)	..	1,000 0 0
,, Salaries, Wages and Retiring Allowances—		
Salaries	4,372 10 0	
Retiring Allowances	1,605 0 0	
Clerks, Messengers and Housekeeper	4,838 16 6	
		10,816 6 6
,, Premiums on Policies for Staff Pensions—		
Portion paid by the Institution	..	1,395 18 7
,, Stationery, Postages, etc.—		
Stationery and Printing	1,182 4 2	
Postages, Telegrams and Parcels	682 17 8	
		1,865 1 10
,, Publications—	£ s. d.	
Minutes of Proceedings	4,391 3 7	
Selected Engineering Papers	650 11 1	
Sessional Notices	521 10 1	
Charters, By-laws and Lists of Members	416 1 6	
Subject-Index, Vols. 205-218	9 9 6	
Abstracts	2,308 13 3	5,988 15 9
Less Repayment of Transmission Charges	264 2 6	
	2,044 10 9	
Clerical Pay	330 0 0	
	2,374 10 9	
		8,363 6 6
,, Engineering Conference, 1921	..	350 11 3
,, Library—		
Books and Periodicals	374 1 3	
Binding	46 4 0	
Clerical Pay	611 5 0	
		1,031 10 3
,, Examination Expenses		
Examiners, Printing and General	1,208 16 7	
Clerical Pay	805 1 0	
		2,013 17 7
,, Conversazione and Annual Dinner	..	1,283 15 7
,, Diplomas and Medals—		
Diplomas	44 5 0	
Watt and Stephenson Medals	29 10 0	
		73 15 0
,, Local Associations—		
Grants to Local Associations, etc.	..	827 12 6
,, Contributions towards Advisory Committees in the Colonies	..	100 6 3
,, Heat-Engine Trials Committee	..	551 16 2
,, Grants and Contributions—		
Westminster Hospital	10 10 0	
Marine Biological Association	100 0 0	
Optical Convention, 1926	26 5 0	
		136 15 0
,, Legal and other Professional Charges—		
Legal Charges	409 12 5	
Auditor's Fee	157 10 0	567 2 5
,, Interest on Loans	..	825 14 10
		39,409 4 11
,, Balance carried to Capital Account	..	1,941 8 1
		£41,350 13 0

Digitized by Google

FROM 1st APRIL, 1925, TO 31st MARCH, 1926.

INCOME.

	£ s. d.	£ s. d.
By Subscriptions applicable to the Financial Year 1925–1926	..	35,318 15 9
,, Membership Fees	..	1,763 9 0
,, Interest, Dividends, etc.—		
On Institution Investments	894 10 4	
On Deposit	267 14 7	
Income Tax Refunded for the year 1924–25	118 2 6	
		1,280 7 5
,, Examination Fees		2,497 5 0
,, Minutes of Proceedings (Repayment for Binding)	..	269 18 4
,, Library Fund Donations	..	58 7 6
,, Rent of 1, Great George Street	..	162 10 0
		£41,350 13 0

Digitized by Google

TRUST FUND CAPITAL ACCOUNTS AT 31st MARCH, 1926.

	£	s.	d.
Telford Fund	7,988	9	4
Manby Donation	270	0	0
Miller Fund	4,850	2	4
Howard Bequest	500	0	0
Trevithick Memorial	100	0	0
Crampton Bequest	500	0	0
James Forrest Lecture and Medal Fund	1,104	14	0
Palmer Scholarship Fund	1,430	18	0
John Bayliss Bequest	1,000	0	0
The Indian Fund	1,148	11	8
Vernon-Harcourt Bequest	1,000	0	0
Webb Bequest	1,000	0	0
Yarrow Educational Fund	10,049	9	6
William Lindley Fund	1,435	4	9
Kelvin Medal Fund	475	0	0
Charles Hawksley Bequest	3,000	0	0
Coopers Hill War Memorial Fund	1,101	6	5
As per Balance Sheet, page 288	£36,953	16	0

INSTITUTION INVESTMENTS AT 31st MARCH, 1926.

£	s.	d.		COST. £	s.	d.
3,000	0	0	Metropolitan Water Board 3% "B" Stock	2,958	16	0
6,000	0	0	London and North Eastern Railway 4% Debenture Stock	7,749	18	3
6,000	0	0	London, Midland and Scottish Railway 4% Debenture Stock	7,452	14	8
10,480	18	6	War Stock 5% 1929-1947	10,160	17	9
581	6	7	Do. (Repairs and Renewals Reserve)	585	15	9
			As per Balance Sheet, page 289.	£28,908	2	5

NOTE.—*The value of these Investments at ruling prices on 31st March, 1926, amounted approximately to* £22,520.

Digitized by Google

TRUST FUNDS INVESTMENTS AT 31ST MARCH, 1926.

	Capital. £ s. d.	*Unexpended Income.* £ s. d.
TELFORD FUND.—£8,738 13*s.* 0*d.* 2½% Consols	7,988 9 4	
MANBY DONATION.		
£250 London & North Eastern Railway 4% 2nd Guaranteed Stock	270 0 0	
MILLER FUND.		
£5,129 17*s.* 5*d.* 2½% Consols	4,850 2 4	
£1,045 18*s.* 6*d.* War Stock 1929-1947	..	1,037 10 0
HOWARD BEQUEST.—£551 14*s.* 6*d.* 2½% Consols	500 0 0	
TREVITHICK MEMORIAL.—£103 2½% Consols	100 0 0	
CRAMPTON BEQUEST.—£512 15*s.* 11*d.* 2½% Consols	500 0 0	
JAMES FORREST LECTURE AND MEDAL FUND.		
£465 Southern Railway 4% Debenture Stock £531 1*s.* 0*d.* 5% War Stock 1929-1947	1,101 14 0	
£99 10*s.* 0*d.* 5% War Stock 1929-1947	..	100 0 0
PALMER SCHOLARSHIP.		
£1,496 6*s.* 1*d.* Metropolitan 3% Consolidated Stock	1,430 18 0	
£99 10*s.* 0*d.* 5% War Stock 1929-1947	..	100 0 0
JOHN BAYLISS BEQUEST.		
£1,013 17*s.* 10*d.* London County 3% Stock	1,000 0 0	
£79 12*s.* 1*d.* 5% War Stock 1929-1947	..	80 0 0
THE INDIAN FUND.—£1,353 4*s.* 2*d.* 2½% Consols	1,148 11 8	
£99 10*s.* 0*d.* 5% War Stock 1929-1947	..	100 0 0
VERNON-HARCOURT BEQUEST.		
£1,082 9*s.* 10*d.* London County 3% Stock	1,000 0 0	
WEBB BEQUEST.		
£1,055 7*s.* 2*d.* Metropolitan Water Board 3% "B" Stock	1,000 0 0	
£99 10*s.* 0*d.* 5% War Stock 1929-1947	..	100 0 0
YARROW EDUCATIONAL FUND.		
£4,205 London, Midland & Scottish Railway 4% Preference Stock £2,110 London & North Eastern Railway 4% 1st Preference Stock £2,110 London & North Eastern Railway 4% 2nd Guaranteed Stock	10,049 9 6	
WILLIAM LINDLEY FUND.		
£1,000 10*s.* 0*d.* London, Midland & Scottish Railway 4% Debenture Stock	1,435 4 9	
£213 10*s.* 0*d.* London, Midland & Scottish Railway 4% Debenture Stock	..	149 11 11
£150 5% War Stock 1929-1947	..	142 10 0
KELVIN MEDAL FUND.		
£500 5% War Stock 1929-1947	475 0 0	
£99 10*s.* 0*d.* 5% War Stock 1929-1947	..	100 0 0
CHARLES HAWKSLEY BEQUEST.		
£955 Metropolitan Water Board 3% "B" Stock £500 South Essex Waterworks 5% Preference Stock £70 5% Sheffield Corporation Water Annuities £40 4% " " "	3,000 0 0	
£993 17*s.* 8*d.* 5% War Stock 1929-1947	..	1,000 0 0
COOPERS HILL WAR MEMORIAL.		
£1,239 15*s.* 0*d.* 5% War Stock 1929-1947	1,101 6 5	
As per Balance Sheet page 289	£36,953 16 0	£2,909 11 11

NOTE.—*The value of these Investments at ruling prices on 31st March, 1926, amounted approximately to £21,883 and £2,987 respectively.*

TRUST FUNDS INCOME ACCOUNTS FROM

Trust Fund.	Balance at 1st April, 1925.		
	£	s.	d.
Telford Fund	105	5	5
Manby Fund	3	18	5
Miller Fund	1,162	15	1
Howard Bequest	52	10	6
Trevithick Memorial	8	13	7
Crampton Bequest	28	17	1
James Forrest Lecture and Medal Fund	119	13	5
Palmer Scholarship Fund	187	12	10
John Bayliss Bequest	83	18	9
Indian Fund	127	7	1
Vernon-Harcourt Bequest	69	14	4
Webb Bequest	232	9	0
Yarrow Educational Fund	55	1	5
William Lindley Fund	483	18	1
Kelvin Medal Fund	165	3	3
Charles Hawksley Bequest	1,035	5	11
Coopers Hill War Memorial Fund	125	2	6
Totals	4,047	6	8

Digitized by Google

1st APRIL, 1925, TO 31st MARCH, 1926.

Income (including Income Tax refunded for the year 1924-25).	Expenditure: Scholarships, Prizes, Lectures, etc.	Balance at 31st March, 1926.
£ s. d.	£ s. d.	£ s. d.
221 3 9	222 7 11	104 1 3
10 5 10	..	14 4 3
183 15 9	131 10 6	1,215 0 4
15 2 10	..	67 13 4
2 16 2	..	11 9 9
13 11 2	15 0 0	27 8 3
50 19 10	47 9 6	123 3 9
52 2 5	50 0 0	189 15 3
30 2 5	30 0 0	84 1 2
39 10 0	33 0 0	133 17 1
29 12 2	..	99 6 6
37 4 3	31 10 0	238 3 3
343 6 6	378 0 10	20 7 1
61 18 6	..	545 16 7
31 13 2	..	196 16 5
209 8 8	..	1,244 14 7
65 4 5	30 19 11	159 7 0
1,397 17 10	969 18 8	*4,475 5 10 *As per Balance Sheet, p. 288.*

* Of which £2,909 11*s.* 11*d.* is invested (*see page 295*).

Digitized by Google

ACCOUNT OF THE COMMITTEE ON THE DETERIORA-

FROM 1ST APRIL, 1925,

	£	s.	d.
To Amount expended during the year to 31st March, 1926. . .	1,409	5	2
„ Balance *carried down*	317	6	1
	£1,726	11	3

Digitized by Google

TION OF STRUCTURES EXPOSED TO SEA ACTION, TO 31ST MARCH, 1926.

	£	s.	d.
By Balance, as per last Account	715	19	8
„ Grant from the Department of Scientific and Industrial Research	260	0	0
„ Subscriptions	734	15	0
" Interest on Deposit	15	16	7
	£1,726	11	3
„ Balance *brought down*	£317	6	1

Digitized by Google

ORIGINAL COMMUNICATIONS.

RECEIVED BETWEEN 1 APRIL, 1925, AND 31 MARCH, 1926.

AUTHORS.

Angwin, A. S., and Walmsley, T. No. 4,562.—Rugby Radio Station. With 9 photographs, 15 prints, 4 drawings, 2 diagrams, and an abstract.

Batchelor, E. No. 4,578.—The Relation of the Yield of a Catchment to its Climate, Soils, and Configuration. With a diagram and an abstract.

Bayley, V. No. 4,588.—The Khyber Railway. With 14 tracings and an abstract.

Beard, S. R. H. No. 4,558.—Lome Pier. With 10 prints, 2 drawings, 8 sheets of photographs, and an abstract.

Bellamy, H. E. No. 4,574.—The Tod River Water Scheme, South Australia. With 26 photographs, 3 maps, 8 tracings, and an abstract.

Bengough, C. F. No. 4,573.—High Level Bridge, Newcastle-upon-Tyne. Underpinning and Repair of Foundations of River Piers. With 7 tracings and an abstract.

Bertlin, P. W. No. 4,557.—Construction of the New Entrance to Tranmere Dock. With 3 diagrams, 4 sheets of tracings, and an abstract.

Burdett, H. L. No. 4,594.—The Roads of Basutoland. With an abstract.

Carolin, C. G. S. No. 4,596.—Maintenance of Electric Installation in the East.

Clark, G. M. No. 4,584.—The Absolute Efficiency of Steam Engines and a Comparison of Temperature and Pressure for Saturated Steam. With a diagram and an abstract.

Dalby, W. E. No. 4,565.—The Mechanical Properties of Steel. With an album of photographs and an abstract.

Everatt, E. L. No. 4,600.—Maintenance Dredging in Bombay Harbour and Docks, and Upkeep of the Navigational Lighting of the Port. With 5 illustrations and an abstract.

Fryer, P. W. No. 4,571.—Notes on Repairs to the Entrance of Lyttelton Graving Dock. With 3 tracings and an abstract.

Digitized by Google

AUTHORS.

Garth, H. R. No. 4,598.—Strainmeter Tests of a Railway Bridge. With 3 sheets of tracings, a print containing 4 diagrams, and an abstract.

Goldson, J. W. No. 4,599.—Mass Concrete. With an abstract.

Gordon, J. W. No. 4,597.—Photographic Tacheometry: the Parallacter Method. With 2 sheets of photographs and an abstract.

Greene, L. K. No. 4,563.—Front Wheel Brakes for Automobiles. With an abstract.

Hearn, G. R. No. 4,590.—The Survey and Construction of the Khyber Railway. With 2 photographs, 2 tracings, an index card, 6 prints, and an abstract.

Hiley, A. No. 4,572.—Analysis of the Supporting Value of Piled Foundations, with Particular Reference to an Improved Method of Casting Concrete Piles in Situ. With 22 photographs, 16 prints, and an abstract.

Howland, R. C. J. No. 4,587.—The Vibrations of Frames. With 5 diagrams and an abstract.

Kent, C. G. No. 4,583.—The Timbering of Trenches, Shafts, and Tunnels. With 2 sheets of drawings, 10 photographs, and an abstract.

Lea, F. C. No. 4,586.—The Effect of Heat Treatment of Cold Drawn Steel Tubes on the Static Properties and their Resistance to Repetition Stresses. With 4 sheets of photographs and 23 blue prints.

Leeming, E. L. No. 4,589.—The Superelevation of Highway Curves. With 3 sheets of diagrams and an abstract.

Lupton, H. R. No. 4,595.—The Triple Expansion Steam-Engine as Applied to the Pumping of Water, with Special Reference to the Plant at Lea Bridge. With 6 sheets of diagrams, a sheet of test figures, and an abstract.

Muirden, M. A. No. 4,579.—Screw-Pile Mooring-Berths. With 2 tracings and an abstract.

Naylor, T. M. No. 4,576.—Whirling and Vibrating Speeds of Loaded and Unloaded Shafts. With a tracing and an abstract.

Pegg, H. V. No. 4,559.—Drift Sand. With a tracing.

Porter, J. P. No. 4,591.—Bridge Foundations on Transported Chalk (with Notes on Piled and Monolith Foundations). With 5 sheets of tracings and an abstract.

Preston, F. W. No. 4,567.—Design of Reinforced Concrete Beams. With 3 diagrams.

Digitized by Google

AUTHORS.

Preston, F. W. No. 4,575.—Design of Plate Glass Polishing Machines. With 28 prints.

Prowde, O. L. No. 4,568.—The Gezira Irrigation Scheme. With 7 tracings and an abstract.

Quintin, W. G. No. 4,577.—Note on the Uniform Flow of Water and Relationship between Bed Width and Depth for Regime Channels. With 2 tracings and an abstract.

Reeson, J. N. No. 4,566.—The Influence of Electric Welding in the Design and Fabrication of Plant and Structures. With 2 prints, 3 drawings, an album of photographs, a bottle of specimens, and an abstract.

Robertson, D. I. C. No. 4,581.—The Cementation of the Glasgow District Subway Tunnels. With 2 tracings, 5 charts, and an abstract.

Smith, T. K. No. 4,564.—The Mathematical Treatment of the Heating and Cooling of Metal Ingots and Plates. With 25 diagrams and an abstract.

Spring, Sir Francis J. E. No. 4,585.—Madras Harbour: A Head for the New Arm Sheltering the Reformed Harbour Entrance. With a diagram and an abstract.

Stewart, J. E. No. 4,582.—The Construction of Trunk Roads. With a blue print and an abstract.

Taylor, J. R. No. 4,560.—Jharia Coal Fields Water-Supply Scheme. With 3 tracings, 5 blue prints, 23 drawings, and an abstract.

Taylor, W. T. No. 4,570.—Calculation of Sags and Tensions for Overhead Electric Power Transmission Lines. With 2 diagrams and an abstract.

Thomson, W. R. No. 4,561.—The Theoretical Aspect of Steam Raising from Waste Heat. With 9 charts and an abstract.

Tuffley, A. E. No. 4,592.—The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland. With 7 sheets of tracings.

Walker, W. J. No. 4,569.—Suggested Standard Cycle for all Types of Internal Combustion Motors. With a sheet of diagrams and an abstract.

Walmsley, T. *See* Angwin and Walmsley.

Weight, W. C. No. 4,593.—Dredging at Mormugao Harbour.

White, C. R. No. 4,580.—Construction of a Breakwater-Head at Madras. With 6 tracings and an abstract.

Wickham, J. T. No. 4,556.—A Relative Solution of Lake Effect on the Flow of the Shannon River and the Natural Storage of the Lakes. With 3 diagrams and an abstract.

Digitized by Google

EXTRA MEETING.

26 October, 1926.

Sir WILLIAM HENRY ELLIS, G.B.E., D.Eng., President, in the Chair.

THE JAMES FORREST LECTURE, 1926.

The PRESIDENT, in calling upon the lecturer to deliver the Thirty-Second James Forrest Lecture, said that he would not attempt to introduce so well-known a personality as Senator Marconi, whose presence that evening the members regarded as an honour.

"Radio Communications."

By Senator GUGLIELMO MARCONI, G.C.V.O., D.Sc., LL.D., Hon. M. Inst. C.E.

I VERY greatly appreciate the honour of having been called upon to deliver this year's James Forrest Lecture before The Institution of Civil Engineers.

I have naturally chosen for my discourse the subject of Radio Communications, which has become a most important science and industry, and which, whilst being still dependent for its future advance and development on scientific research and speculation, already requires for its practical and successful working the sound application of good engineering principles and knowledge.

In the very early days of "Wireless," when electric waves were first beginning to be employed for practical purposes, we only spoke of "Wireless Telegraphy," but with the advance of the art electric waves have been more and more widely utilized, not only for wireless telegraphy, but also for wireless telephony and broadcasting, direction-finding at sea and in the air, for the control of mechanisms at a distance, such as targets, torpedoes, flying machines, and other similar devices used principally for war purposes, and, more recently, also for the transmission of pictures and facsimilies, and television.

I hope you will not think me too visionary if I say that it may be possible that some day electric waves may also be used for the

Digitized by Google

transmission of power, over moderate distances, should we succeed in perfecting devices for projecting the waves in parallel beams in such a manner as to minimize the dispersion and diffusion of energy into space.

The achievements and possibilities of radio transmission have already become so vast, so far reaching, and so complex, that you will easily understand that, did I not confine myself to a very small part of the subject, I could not within the practical limits of this Address give you any detailed information of the numerous engineering difficulties which we have had to face and have endeavoured to solve. I therefore propose merely to skim over my subject, just pointing out some of the difficulties we have had to contend with and how we believe we have been able, in some measure at least, to overcome them.

I think we are still far from being able to say that wireless is based on well-understood foundations, unless of course we should go back to the arrangements used in the past which, to my mind, have become more or less obsolete. There is no doubt that, speaking generally, radio engineers four or five years ago thought they knew much more about the subject than we think we know to-day. Laws and formulas were announced and accepted, showing which wave-lengths were best adapted for various distances, and indicating what amount of power would be necessary in order to be able to communicate over any given distance; but unfortunately it soon became apparent that the logical application of these laws and formulas brought us to the necessity of employing, for long-distance transmissions, such enormous and expensive aerial systems and such large amounts of power as to make the method so costly in capital expenditure and operation that only a very small margin of profit would remain when the system was worked in competition with modern cables and land lines.

These high costs made it very difficult, if not impossible, to bring about any substantial reduction of telegraph rates, which has always been one of my principal aims from the time when I first demonstrated the possibility of establishing a wireless telegraph service between England and America.

I am convinced, however, that now the whole theory and practice of long-distance radio communication is undergoing a most radical and beneficent change, or what we might be quite justified in terming a revolution.

The upsetting of so many pet theories is having the welcome result of increasing the efficiency and usefulness of wireless telegraphy to an enormous and almost unhoped for extent, whilst at the same

Digitized by Google

time opening up what may prove to be fertile fields for research and disclosing an entirely new horizon to our view.

You will perhaps forgive me if I recall that when lecturing before the American Institute of Electrical Engineers in New York, over four years ago, I stated—in referring to some experiments on very short waves which I had been carrying out for some years previously—that I felt we had perhaps got rather into a rut by confining all our researches and tests to long waves, because I thought that the study of short waves, although sadly neglected all through the history of wireless, was still likely to develop in many unexpected directions and to open up new fields of profitable research.

That the minds of some radio engineers had apparently got into a rut seems to be evident by the statement made in my presence by an eminent expert who, in the spring of 1924, on an important occasion stated that in his opinion there was in wireless very little really revolutionary to come, and that he was rather of the school who thought that the saturation point had been reached and that wireless which was then already 25 years old had approached a stable condition.

Commercial long-distance wireless telegraphy has been carried out up to very recently exclusively by stations employing wave-lengths from 8,000 to about 30,000 metres, and using several hundreds of kilowatts at the transmitting end. The latest and largest station of this type in England is the Post Office wireless station at Rugby which, in normal conditions, has a world-wide range throughout the whole of the 24 hours. The aerial at this station is supported by eight towers each 820 feet high, and the total power used for transmitting and auxiliary services amounts to about 1,400 kilowatts, of which 500 kilowatts is fed to the aerial for radio-telegraphic purposes. The wave-length used for the transmission of messages is of 18,740 metres.

The Carnarvon station, owned by the Marconi Company, and used for communicating with the United States, employes a wave-length of 14,080 metres. Its aerial is supported by sixteen towers or masts 400 feet high, and the power used is 305 kilowatts.

The station at Buenos Aires, in the Argentine, designed for communicating with Europe over a distance of about 6,000 miles, employs 800 kilowatts of electrical energy and an aerial supported by ten towers each about 680 feet high. This station normally works on wave-lengths of about 12,000 and 16,000 metres.

Many other stations of similar size and type are operating in the United States, Germany, France, Italy, and in some other countries.

Digitized by Google

Their cost is something of the order of £500,000 each, but considering that their speed of transmission is not very high, their cost and their running expenses, which necessarily include interest on capital outlay, depreciation, and power-consumption, have been found to be high.

Ten years ago, during the war, I began to consider the possible alternative which might be offered by an exploration of the capabilities for point-to-point communication of those electric waves which had never yet been used for practical radio-telegraphy, that is, waves only a few metres in length, and I was particularly attracted to this line of research because I was, of course, well aware that with these waves, and these waves only, it would be possible to project most of the radiation in a narrow beam in any desired direction, instead of allowing it all to spread in every direction.

I was greatly impressed by the advantages which such a system would possess, if found workable, through the saving of energy which might result, and also by the possibility of reducing tapping or interference together with mutual interference between stations, even if working on very small differences of wave-length.

During some of my first experiments on these lines, carried out in Italy, and during subsequent tests, I was most valuably assisted by Mr. C. S. Franklin of the Marconi Company.

These researches were continued by Mr. Franklin in consultation with me at Carnarvon, and in 1917, with a wave-length of 3 metres, a range of over 20 miles was readily obtained when using a reflector at the transmitting end only. Mr. Franklin has since followed up the subject with great thoroughness, and in further radio-telephonic tests in June, 1920, obtained strong and clear speech in Kingston harbour, over a distance of 74 miles from the sending station. In August, 1921, he repeated these tests over a land range of 97 miles between Hendon and Birmingham.[1]

I might point out that there was nothing to indicate to us that these distances constituted the limit of the range of the waves employed. This could only be satisfactorily tested and ascertained by means of a movable station, and with this object in view tests were commenced by myself and Mr. Franklin in the spring of 1923, by means of a special receiving station installed on the S.Y. "Elettra."

In the Hendon–Birmingham experiments the increased efficiency brought about by the use of reflectors was confirmed, and clearly demonstrated by average measurements which showed that the

[1] C. S. Franklin, "Short-Wave Directional Wireless Telegraphy," Journal Inst. Elec. E., vol. 60 (1922), p. 930.

Digitized by Google

intensity of the energy received when reflectors at both the transmitting and receiving stations were employed was 200 times that of the energy which could be received with no reflectors.

During April, May, and June, 1923, a systematic series of long-distance tests was carried out over varying distances between a small experimental transmitting beam station at Poldhu in Cornwall, and a receiving station installed on the S.Y. "Elettra."

A wave-length of approximately 92 metres was employed, and it was soon ascertained that the Poldhu signals could be clearly and reliably received during daylight up to distances of 1,250 nautical miles.

The Poldhu sending station was at that time using about 12 kilowatts in the aerial. The night signals came in always with great strength and regularity up to the maximum distance to which the yacht was able on that occasion to proceed, which was as far as the Cape Verde Islands, situated 2,320 nautical miles from Poldhu, and the strength of the signals received there left no doubt in my mind that the practical range of the signals was very greatly in excess of that distance.

I think I am right in saying that up to that time the general impression prevailing amongst most technical experts in regard to the behaviour of short waves was :—

(1) That their range during daytime would be very short.

(2) That the night ranges, although occasionally considerable, would be exceedingly variable and freaky, and therefore altogether too unreliable to allow these waves to be of any use for long-distance commercial working.

(3) That any considerable stretch of intervening land, especially if mountainous, would seriously reduce the distance over which it might be possible to communicate.

The 1923 tests, carried out between Poldhu and the "Elettra," had the result, however, of completely convincing me and my assistants that the above impressions or conclusions were quite wrong in so far as they concerned waves of about 100 metres or less, for we observed :—

(1) That the daylight ranges proved to be very much greater than had been anticipated.

(2) That the night ranges were reliable and not variable or freaky, besides clearly indicating that the possible distances which could be covered would be very much greater than anyone, including myself, had been led to expect.

(3) That intervening land and portions of continents did not constitute an obstacle to the propagation of these waves.

Digitized by Google

Moreover, a fact more or less expected was also observed, and this was, that even in the tropics, atmospheric electrical disturbances, or X's, were always very much less troublesome when receiving on short waves than those experienced with the much longer waves which, at that time, were being used exclusively for all practical long-distance radio-telegraphy.

The variations of strength, and what is now termed "fading," were proved to be very much less serious than I had anticipated, and results obtained over even the maximum distances could always be repeated during the many weeks these tests lasted.

The results of the "Elettra" tests were set forth in a technical report, drawn up at that time, and were also described in detail in a Paper which I read before the Royal Society of Arts on the 2nd July, 1924.

In this Paper I ventured to predict that, by means of these comparatively small-power stations, a far greater number of words per 24 hours would be transmitted and received between England and her distant Dominions than would be possible by the then existing or proposed powerful and expensive long-wave stations.

This may perhaps have been a bold statement, but I felt sure it was going to be justified by results.

These tests were continued in February and March, 1924, with the object of determining the maximum practical range of these waves, independently from any advantage to be gained by the use of reflectors or directional methods, and we found that, whilst the day range of a 92-metre wave was about 1,400 nautical miles at that time in the North Atlantic, good communication could be established during the dark or semi-dark hours with the United States, the Argentine, and Australia, that is, across world-wide distances.

During these tests a wireless-telephony experiment was also carried out with Sydney, when, for the first time, intelligible speech direct from England was received and understood in Australia.

In August and September, 1924, further tests were carried out between Poldhu and the S.Y. "Elettra," with the object of endeavouring, if possible, by the employment of still shorter waves, to overcome the limitation of the hours of working brought about by the effects of daylight, for, of course, we realized that this limitation of the period of working to practically only the hours of darkness constituted the one serious drawback in the way of the general adoption of the new system.

Tests were therefore carried out over varying distances with four wave-lengths of 92, 60, 47, and 32 metres respectively. These tests enabled me to discover the important fact that over long distances

Digitized by Google

the daylight range of practical communication steadily increased as the wave-length was reduced below 92 metres, the 32-metre wave being received all day at Beirut in Syria, over a distance of 2,100 miles, whilst the 92-metre wave began to fail over this track, which is mostly across land, at a distance not much in excess of 1,000 miles.

At the same time, the 60-metre wave appeared to be slightly better than the 92-metre during daylight, the 47-metre still better, and the 32-metre very much better. We naturally presumed, and later experience confirmed our anticipation, that still shorter wave-lengths would be affected by daylight to an even lesser degree.

It was therefore proved to our satisfaction at least, that daylight absorption decreased very rapidly with the shortening of the wave-lengths below 92 metres.

This discovery, apart altogether from its practical importance, raises scientific questions of the highest interest in regard to the possible theoretical explanation as to how these waves travel round the earth. It is clear that the results cannot be explained by mere refraction, as the signals received over world distances are many thousand times stronger than they could ever be by mere refraction.

I do not intend, within the limits of time at my disposal during this Lecture, to indulge in any theoretical hypothesis, as I much prefer to confine myself to describing facts and results together with the more or less correct inferences which may be deduced from them, but I may, of course, mention that the generally accepted explanation is that the effect must in some way or other be due to the ionization of the high-level atmosphere, which is supposed thereby to constitute a conducting layer of rarefied and ionized gases, forming a kind of shell concentric to the surface of the earth and capable of reflecting, or bending, the waves. Such a conducting layer is often referred to as the "Heaviside Layer."

In October, 1924, transmission tests were carried out on a wave-length of 32 metres to specially installed receivers at Montreal, New York, Buenos Aires, and Sydney (Australia), and it was at once found to be possible to transmit messages, when utilizing only 12 kilowatts or less at the transmitter, to New York, Rio, and Buenos Aires, even when the whole of the great circle track separating these places from Poldhu was entirely exposed to daylight.

With Australia, however, it is only possible to have a complete daylight track for 2 or 3 hours at a time, and, further, the scientific aspect of the test is complicated by the fact that the waves have several ways of getting round, with comparative ease, if they can get there at all, as a large portion of Australia is not very far from the

Digitized by Google

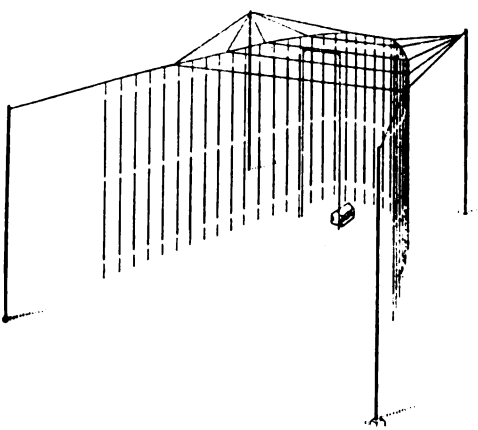
antipodes of England. The Australian tests showed, however, that it was possible to get through for about 23¼ hours out of the 24.

I would like to point out that most of these very long-distance tests were carried out without the use of reflectors at either end, and merely with the object of ascertaining the range and general capabilities of these waves.

In these first beam experiments carried out in Italy and in England, the reflectors were constituted by a number of vertical wires parallel to the antennæ and spaced around them on a parabolic curve of which the transmitting or receiving antennæ constituted the focal line (*Fig. 1*), but in the more modern stations an arrangement devised by Mr. Franklin has been more advantageously employed.

In this arrangement the antennæ and the reflector wires are disposed so as to constitute grids parallel to each other, the aerials

Fig. 1.



or antennæ being energized simultaneously from the transmitter at a number of feeding points, through a special feeding system, so as to secure that the phase of the oscillations in all the wires is the same (*Fig. 2*). It has been proved by calculations and confirmed by experiments that the directional effect of such an arrangement is a function of its dimensions relative to the wave-lengths utilized.

A similar system of aerials and reflecting wires is used at the receiving stations.

For a more complete account of the results of the investigations which I was able to carry out in 1924, together with a more detailed description of the general principles on which short-wave directional wireless transmission is based, and also in regard to the apparatus

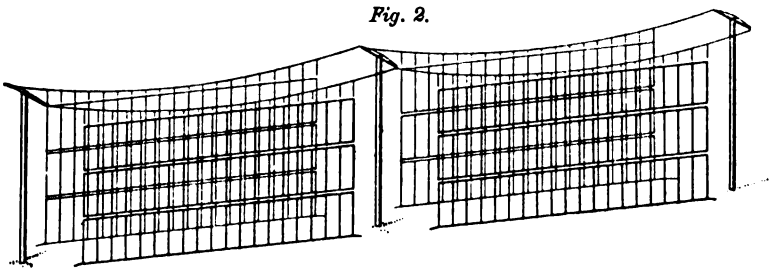
Digitized by Google

employed, I would refer to my two Papers read before the Royal Society of Arts on the 2nd of July, 1924, and the 11th of December of that same year,[1] and to Mr. Franklin's Paper already referred to.

As already pointed out, it had been proved long ago by calculations, confirmed by experiments, that the directional effect of a radio reflector is a function of its dimensions in relation to the wave-length employed. Hence it follows that the dimensions of the aerial and reflectors can be reduced proportionately to that of the wave-length, and, therefore, the cost is much lower and space occupied is much smaller for wave-lengths of say 20 metres than for wave-lengths of say 90 metres.

In the spring of 1924 a Sub-Committee of the Cabinet was appointed for the purpose of considering proposals made by the Marconi Company for the employment of the short-wave beam system for Imperial communications, and on the 2nd July of that year an agreement was entered into between the Post Office and the Com-

Fig. 2.



pany for the construction of wireless stations on this system capable of communicating to and from Canada, South Africa, India, and Australia

This contract stipulated that the transmitting stations were to dispose of a power of 20 kilowatts to be delivered to the anodes of the valves used for generating the oscillations, the aerial-system to be so designed as to concentrate the emitted waves within an angle of 15 degrees on either side of the axis of the transmission ; the energy of radiations beyond this angle not to exceed 5 per cent. of those on the axis ; the receiving section to have a similar aerial-system designed to have its maximum receiving power in the direction of the corresponding station. The station for corresponding with Canada was to be capable of sending and receiving at the same time to and from the Canadian station one hundred words of five letters

[1] "Results obtained over Long Distances by Short Wave and Directional Wireless Telegraphy," Journal Roy. Soc. Arts, vol. 72 (1924), p. 607, and "Radio Communications," *ibid.*, vol. 73, p. 121.

Digitized by Google

each per minute (exclusive of any repetitions necessary to secure accuracy) during a daily average of 18 hours, and the Company was to give a demonstration to the Post Office by actual working for 7 consecutive days that these severe conditions could be fulfilled. The stations were to be worked by what is termed " remote control " through land lines from the Central Telegraph Office in London, and the received signals were to be capable of working a high-speed recording instrument also in the same office in London.

If the Engineer-in-Chief of the Post Office was satisfied that the results of the 7 days' working complied with the terms of the contract, the stations were to be handed over to the Post Office and half the purchase price paid to the Company, the other half to be paid in the course of 1 year afterwards, if the system continued to fulfil the conditions of the contract.

The preliminary certificate that the stations had complied with the conditions during the 7 days' official test was received from the Engineer-in-Chief of the Post Office on Monday the 18th of the present month.

The English beam transmitting stations for Imperial communication, completed or still in course of construction, are (*Fig. 3*) at Bodmin for working with Canada and South Africa, and at Grimsby, for working with Australia and India, the corresponding receiving stations being at Bridgewater and Skegness. Moreover, another beam station is in course of erection at Dorchester, for working to the United States and to South America. Arrangements and agreements were also completed for the construction of similar corresponding stations in Canada, South Africa, Australia, and India.

The Bodmin station is situated on a strip of land bordering on the main Bodmin–Truro road, 4½ miles south-west of the Cornish county town, from which the station takes its name.

Each aerial and reflector system, i.e., the one for Canada and the one for South Africa, is supported by a row of five stayed lattice steel masts, so arranged that the great circle bearing to the distant station with which that particular station is intended to work is at right angles to the line of the masts.

The design of the aerial and reflector system is identical at both the transmitting and receiving stations. The masts have an overall height of 287 feet to the top of the cross arms, and are spaced at a distance of 650 feet from each other.

The high-frequency current is conveyed to and from the aerials through what is termed a " feeder system," consisting of concentric copper tubes, air insulated from each other to avoid loss. The outer tube is earthed and carried on iron standards driven into the ground.

Digitized by Google

The inner tube, which constitutes the conductor, is kept in position and insulated from the outer tube by porcelain spacing insulators.

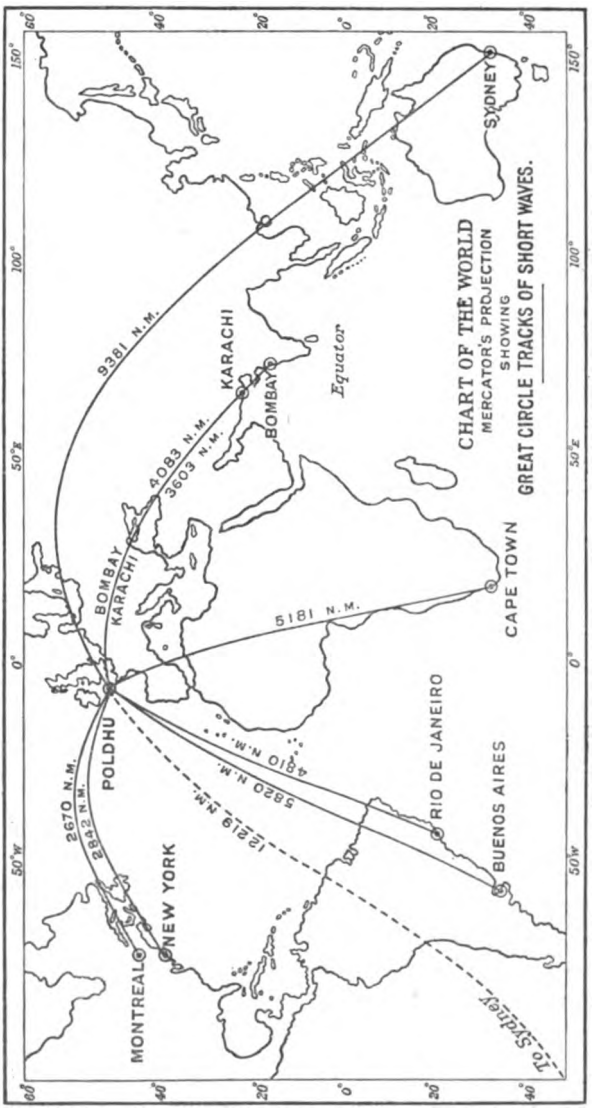


Fig. 3.

The length of feeder tube from the transmitter to each individual aerial wire is arranged to be exactly the same. Thermionic valves are used to generate the extra-high-frequency oscillations, and

Digitized by Google

oil-cooled valves are employed on the main circuits in preference to water-cooled valves, because in short-wave work oil is easier to handle besides being an insulator in itself. The wave-length at present used on the Canadian service is 26·09 metres, or 11,500 kilocycles on the Bodmin transmitter, and 26·27 metres, or 11,420 kilocycles, on the Canadian transmitter.

It is obvious that I have not even attempted to give a proper technical description of these stations, nor have I said anything of the buildings, power-plant, switchboards, rectifiers, keying systems, controls, etc. To describe these important items and the receiving stations, together with an even brief account of all the engineering difficulties which have had to be faced and overcome, would require more than one lengthy Lecture.

I hope that Mr. Franklin, who has to his credit the design of most of the arrangements employed, especially on the technical and scientific side, and Mr. R. N. Vyvyan on the engineering side, will soon be able to find time to prepare and publish a more complete description of these stations.

Numerous tests have been carried out at intervals since last July, and the official 7-day test for the Post Office took place between the 7th and the 14th of this month. Conditions, which were very stringent, and to which wireless over short or long distances had never before been subjected, were successfully complied with.

During these and the preliminary tests, speeds of 1,250 letters per minute in each direction, equal to 2,500 letters per minute over the whole circuit, have been worked without an error for hours on end. Counting every hour of the 7-day test, the average speed of signalling has been about 650 letters per minute in each direction, or 1,300 letters per minute over the complete circuit.

The Bodmin and Bridgewater stations have now been taken over by the Post Office, and the new service was opened to the public last Sunday midnight, the 24th October.

These results have been of the greatest possible satisfaction to myself and my co-workers, because they go to prove that our faith in the new system, which we have held for years in the face of much scepticism and criticism, was not altogether misplaced.

The working of these beam stations has already shown some further very interesting results, some of which are, perhaps, novel in the history of long-distance wireless. One of these is in regard to atmospheric disturbances, or X's. I think we all know that "atmospherics" have all along been the bugbear of wireless, but we have noticed that with these types of stations they have been very much less severe than in any other long-distance receivers with

Digitized by Google

which we have ever had experience. Thunderstorms in the vicinity of the receiving station do not cause much interference, unless (and it seems to be a rare occurrence) they should be inside the angle of receptivity of the receiving reflector and not too far off.

I feel confident that the disturbances usually known as "atmospherics," as apart from fading, have ceased to exist as a serious hindrance to the working of high-speed radio between England and Canada. I fully realize that this is a bold statement, but I feel pretty confident I am right in making it.

The variations, or rather, the "attenuation" of signal intensity, now termed "fading," has been a marked feature of long-distance radio-transmissions, especially when short waves are employed, and although in my experience "fading" appears to be worse with wave-lengths between 200 and 1,000 metres, it has sometimes occurred on the 26-metre wave, which is utilized by the beam stations working between England and Canada.

According to the experience of myself and my collaborators, the use of reflectors has the advantage, which perhaps is common to all sharply directional systems, of diminishing "fading." This is brought about partly, no doubt, by the great increase of the received signal-strength which is obtained by the utilization of this directional system, and which thereby increases the margin of readability of the received signals. It is, however, a fact that "fading" does to a certain extent still exist on the Bodmin–Canada circuit, and, on certain occasions, has even cut off all communication between the two stations. Two such bad periods of "fading" occurred on the 20th of September, and on the 14th of October. Both these bad periods coincided with the appearance of very large sun-spots and intense aurora borealis, and at the same time telegraph lines, especially in Canada, and cables were thrown out of action, or their proper working was greatly interfered with. I, however, noticed that during these bad periods signals could be received across the Atlantic by using still shorter waves of the order of 15 metres in length, and also that the working of ordinary long-wave stations was not interfered with. As I have already pointed out, waves as short as 15 metres or less can be received across long distances better by daylight than during night-time, and we also know that very long waves are not affected by daylight on the North Atlantic track. The conclusion I come to from these observations is that, during the days when sun-spots and aurora borealis were noticed, conditions, due to ionization of the atmosphere at a certain height resulting in a lowering of the ionized stratum, equivalent to what I might term "intensified daylight," were prevalent.

Digitized by Google

Another "fading" period of a few hours duration, which a newspaper wrongly attributed to "atmospherics," occurred during yesterday's severe storm. We have not yet been able to ascertain to what causes it may be attributable. It may even have been due to some insulation fault. It is, however, obvious that we cannot expect an entirely new system to be perfect from the very start.

Professor Elihu Thomson, in delivering the 1924 James Forrest Lecture before this Institution, stated that it was his opinion that extensive auroral display was coincident with the existence of exceptional areas of disturbance on the sun, and he also referred to the probability under such circumstances of a decided elevation of charge, or potential, of the outer partially-conducting layer 50 or 60 miles above the earth's surface.

Provision has, however, been made for the use of two waves of different length at the beam stations, and a shorter wave will be tested and used during any exceptional conditions of the nature of those I have referred to, whenever they appear to interfere with transmission on the 26-metre wave.

Before concluding this Address, I would like to put before you a few considerations in regard to what I believe to be the relative value of short versus long waves for long-distance radio communications.

We all know that the ether is becoming very congested over a considerable range of wave-lengths, and it may be well roughly to figure out the number of possible wave-lengths, or channels, which can be used without danger of mutual interference. If we assume that long waves may be classed between 5,000 metres and 30,000 metres, and short waves between 5 metres and 100 metres, then by applying the basis of a rule proposed for consideration at the next International Radio Conference, we find that 3,700 wave-bands, or channels, will be practicable and permissible for the short waves between 5 and 100 metres, but only 90 for the long waves between 5,000 and 30,000 metres. This, of course, is rather a conservative estimate of the number of channels, but, should narrower wave-bands be adopted, the proportional permissible number of short waves would bear the same proportion to the possible number of long waves. But, in addition to this very great advantage for the short waves, they have a further one due to the possibility of restricting a large proportion of their power to within a narrow angle, by means of the so-called beam system, and also to the screening effect of the reflector at the receiving station which, by reducing the possibilities of interference, tends still further to increase the number of separate services which can be worked by means of these waves.

Digitized by Google

It should also not be lost sight of that very high speeds of working appear to be only possible if short waves are employed, whilst with the lower frequency of the long waves speeds of the same order are quite unattainable. I might, in other words, state that in regard to the waves there exists no theoretical reason why with a frequency of 3,000,000, such as the frequency of a 100-metre wave, the possible speed should not be 200 times as great as that attainable with a frequency of 15,000, which is a frequency of the order of the main transmitter at the Rugby long-wave wireless station.

The high-power long-wave stations in this country, which at present are carrying out a commercial wireless telegraph service to and from the United States, are capable, I am advised, of transmitting and receiving each way under normal conditions at the same time at an average speed of twenty words per minute for a daily average of 18 hours. But the beam stations on their official tests have already proved capable of sending and receiving at the same time at an average speed of at least 100 words a minute for 18 hours per day, which represents at least five times the traffic which could be handled during the same time by the long-wave stations, although these last employ at least ten times the electrical power used by the short-wave stations.

These figures are, I feel sure, sufficient to show you that the whole art and science of radio-transmission is undergoing at the present time a most profound process of evolution.

There is also another interesting economic feature in regard to long-distance services by means of short waves with respect to cables which should not be overlooked.

With cables the capital cost of the cable itself increases in simple and direct proportion with its length, but in experimenting with short-wave wireless it has been noticed that it is possible to send messages to Australia with an even smaller amount of electrical energy than is necessary to send them to Canada, and therefore at a probably lower cost, or, alternatively, with greater speed and efficiency.

I have often been asked why it is that, if these short waves are capable of covering the greatest distances without employing the beam system, I have always insisted on using it in all the stations my Company is establishing for Imperial and other important long-distance services.

My reasons are that as I have perhaps learned something in regard to the very severe exigencies of modern commercial telegraphy, I have felt that in consequence of "fading" and interference the signals obtained from such stations are not strong enough for

Digitized by Google

high-speed commercial services such as are required between the various parts of your scattered Empire.

It has also been suggested that I might use more power than 20 kilowatts, but this idea never appealed to me, as I consider it would be necessary to use an enormous and impossible amount of power to give the same average signal strength as can be obtained by the use of moderately small power beam stations.

The tests between England and Canada have already shown that the use of beam aerials and reflectors at both ends has resulted in a signal-strength which Mr. Franklin estimates normally to be some 100 times greater than that obtainable with non-directional transmitting and receiving aerials utilizing the same power. Now, since the increase of strength of the received signals rises in proportion with the square root of the power of the transmitter, it is easy to calculate that in order to obtain signals of 100 times the strength it would be necessary to use 10,000 times the energy and, hence, as the power supplied to the anodes of the thermionic valves of the beam station is 20 kilowatts, it would be necessary to use the impossible and absurd power of 200,000 kilowatts with the ordinary all round radiating and receiving stations to give the same average strength of signals at the receiving end.

The results obtained have convinced me that a good directional system is the system of the future for point-to-point radio-communication over long distances throughout the world, and it is most gratifying to me that the British Government and the Governments of the principal Dominions and of India have given me an opportunity of endeavouring to prove it.

I have always felt that wireless waves are far too valuable to be continuously scattered and broadcast equally in all directions instead of being concentrated as much as possible on the station with which one desires to communicate.

I would like to add that I do not think that the beam system is by any means limited to wireless telegraphy. I feel confident that it can be utilized for placing wireless telephony on a much more practical basis than it is on at present, besides helping the systems of picture and facsimile transmission, including television. Even for what is called broadcasting I believe it will result in enabling programmes and speeches to be transmitted to large portions or sectors of the United States, Canada, South Africa, and Australia, with much greater strength and accuracy than is possible with the existing systems of broadcasting.

The results obtained by amateurs by means of short waves do great credit to them, especially if we consider that most amateurs

Digitized by Google

possess only limited facilities for experimental work; and it should not be forgotten that amateurs were the first to carry out two-way communication with New Zealand for brief periods. Their observations have often been of value in helping us to arrive at a somewhat better understanding of the very complex phenomena involved, but I think it is sometimes dangerous to attach too much importance to all their observations, especially when they concern what I might term negative results. Only the other day I read a statement by an eminent authority that, according to amateurs' observations, the daylight range of a 100-metre wave did not exceed 200 miles and for a wave 50 metres long 100 miles. I have carried out tests on a 100-metre wave-length for months on end and have never found its daylight range to be below 1,000 miles. With a 47-metre wave (which is close to 50 metres) we have never observed any skip-distance commencing at 100 miles or at anything like so short a distance. It may well be that some of the observers were not particularly skilled, or were using insensitive receivers, or that their stations happened to be situated near buildings or structures which unfavourably affected receiving. I therefore think it would be unfortunate if, in consequence of some reports, the theory of skip-distances should become unduly generalized and extended.

I have found that for reliable observations and deductions in regard to the behaviour of transmissions over varying distances, there is nothing so good as a receiving station installed on a suitable ship. On a ship, or yacht, one has the advantage of using the identical aerial system, the same receivers, and the same observers throughout at all distances, and this, I think, is a most reliable way of testing the behaviour of these waves over what might be termed intermediate distances.

It is difficult to do this on liners, or even on tramp steamers, as the wireless passenger traffic is likely to interfere very often with the observation of the signals of any particular station under test, and ships of commerce cannot always stop at intermediate ports for short or prolonged observations when and where necessary.

During my first Transatlantic tests with Canada 24 years ago, I had the use of a cruiser placed at my disposal for one year by the Italian Government, and I think warships could often be very profitably employed in helping to clear up many of the wireless mysteries and problems which still await explanation and solution.

I wish to be able to say, before concluding, how much the perfecting and establishment of the beam system owes to the skill and perseverence of many engineers and experts, but in the first place to

Digitized by Google

Mr. C. S. Franklin on the scientific and technical side, to Mr. R. N. Vyvyan, Engineer-in-Chief of the Marconi Company, on the engineering side, and to Mr. A. G. Mathieu for his special work on short-wave receivers.

We are yet, in my opinion, a very long way from being able to utilize electric waves to anything like their full extent. This will be the work of future engineers, and with the continual advance of civilization it will become more necessary in the future than it has been in the past.

Mr. FREDERICK PALMER, Vice-President, said he rose to propose a vote of thanks to Senator Marconi with the greatest pleasure. He could claim no particular knowledge of wireless, but whatever he might lack in knowledge of the subject he made up in enthusiasm. He had been very much interested in the Address because it had often been instructive to him, on his many trips connected with professional work which had taken him to all parts of the world in recent years, to find that wherever he went there was a bulletin of the news of the world every morning at breakfast. On the way home from the Gold Coast a few weeks ago, on calling at Sierra Leone, the passengers obtained in the afternoon the result of the cricket test match against Australia two or three hours after the game was over, and not only the result, but also the details of the score. He thought that was very wonderful. The Institution owed to Senator Marconi another debt of gratitude because he had brought into the building that evening the largest meeting that had ever assembled in it. The attraction of a lecture by Senator Marconi had filled the Great Hall, and he thought he would be voicing the feeling of all present in saying that they were deeply indebted to the lecturer.

The motion having been carried by acclamation,

Senator MARCONI, in reply, said he thanked the President and Mr. Palmer very sincerely for the kind remarks they had made. What he had spoken about that evening was something that the public did not come directly in touch with. They could use it by handing in messages to the Post Office, but they had not the handling of the instruments. That was done by the Post Office, and he hoped that they would be able to work it well! Anyhow, it was necessary to get through about one hundred words a minute all the time, whatever the weather was like; otherwise the thing was not considered a success. That had been the problem. He thanked the audience very much for their attention and for the very kind way in which they had received him.

Digitized by Google

OBITUARY.

Sir PHILIP WATTS, K.C.B., LL.D., F.R.S., was born on the 30th May, 1846. His father, John Watts, was principal assistant to John Fincham, Master Shipwright of Portsmouth Dockyard, and his great grandfather and grandfather were also master shipwrights, the first having been concerned in the building of Lord Nelson's flagship, the "Victory," while Isaac Watts, who was Chief Constructor of the Navy before 1863, was another kinsman.

After being educated privately, he began his pupilage in the Royal Dockyard at Portsmouth in 1863. In 1866 he entered the Royal School of Naval Architecture and Marine Engineering at South Kensington, and he continued his training under the Admiralty until 1870, being engaged upon the design and construction of ships and their machinery. He was appointed third-class draughtsman in 1870, and was associated later with Dr. William Froude, M. Inst. C.E., in experimental tank researches for the Admiralty. Having been promoted to the grade of constructor in 1884, he was appointed in the following year to the staff of Chatham Dockyard.

On the appointment of the late Sir William White, Past-President Inst. C.E., as Director of Naval Construction, Sir Philip succeeded him, in 1885, as organizer and director of the warship building department of Messrs. Armstrong, Whitworth and Company, at Elswick-on-Tyne. Besides being responsible for the design of the numerous warships built by that firm he was occupied with the construction of an extension of the Company's shipyards and engine-shops. The ships built in the Elswick yards under his direction became noted for their remarkable advances in speed and gun-power, combined with small displacement, and Sir Philip's designs rapidly became famous throughout the world. Numerous vessels, principally cruisers of advanced design, were supplied to the navies of states which were not in a position to build their own ships, the more important of these countries being Japan, Argentina, Brazil, Chile, Norway, Portugal, Roumania, and Turkey. Sir Philip was one of the first designers to adopt the four-cylinder type of triple-expansion engine, on account of its improved balance.

Sir William White having, owing to ill health, resigned his post as Director of Naval Construction early in 1902, Sir Philip was again appointed to succeed him. The first battleships for which he was responsible were the "Agamemnon" and "Lord Nelson," and he designed several classes of cruisers, notably the "Duke of Edinburgh" and "Black Prince."

On the appointment of Lord Fisher as first Sea Lord in October,

Digitized by Google

1904, a Committee of Design was formed, which included naval officers, naval architects, and Lord Kelvin, to consider an entirely new type of capital ship. It fell to Sir Philip to give effect to the recommendations of this Committee, and the first of the new battleships was the "Dreadnought," which was commissioned in 1906. The "Dreadnought," unlike her predecessors, had but one calibre of gun in the main armament, which arrangement enabled an improved system of fire-control to be used. She displaced 17,900 tons, and carried ten 12-inch, 45-calibre guns, of which eight could be fired broadside; and her then unusually high speed of 21·6 knots was obtained largely by the adoption—for the first time in a battleship—of Parsons turbines for propulsion. Other noteworthy features of this vessel were her construction in independent and completely watertight compartments, and improved construction of the immersed portion of the hull, adding to the protection against torpedo attack. Following the "Dreadnought," which, as experience has shown, rendered the battleships of all foreign powers obsolete, he designed the "Bellerophon," "St. Vincent," "Neptune," "Orion," "King George V," "Iron Duke," and "Queen Elizabeth" classes of battleships. Simultaneously the design of cruisers underwent radical modification, and in 1906 the "Indomitable," "Inflexible" and "Invincible" were laid down from the designs of Sir Philip Watts, thus creating the modern battle-cruiser. In fact he was responsible for all the battle-cruisers in the Navy at the outbreak of war, from the "Indomitable" to the "Tiger." Of the thirty-four British capital ships engaged in the battle of Jutland, twenty-nine were designed by him, and of the remainder, three had been purchased from foreign powers at the outbreak of war. He was also responsible for the design of other types of vessels, and his department took over the development of the submarine, after early experimental types had been built by private firms.

In 1910 he expressed a wish to retire, but at the request of the Admiralty he retained office for more than a year longer, and he acted in a consultative capacity to the Admiralty until 1916, when he returned to the firm of Armstrong, Whitworth and Company, of which he was a director until his death.

He was elected a member of The Institution in 1901, and was a Member of Council continuously from 1909 to 1918. He was an Honorary Vice-President of the Institution of Naval Architects, into which he was elected in 1873. He was elected a Fellow of the Royal Society in 1900, and became a member of Council and Vice-President of that body, and was also a member of the Institution of Mechanical Engineers. He served on the Council of the Society for Nautical Research, and was Chairman of the Shipbuilding Employers' Federation, 1899–1902, and Master of the Shipwrights Company, 1915–16. He was created a Knight Commander of the Bath in 1905, and Honorary Degrees were conferred upon him by the Universities of Glasgow and Dublin. The Order of the Rising Sun was bestowed upon him by the Emperor of Japan for his

Digitized by Google

services to the Japanese Government in connection with the design of warships.

For many years he was interested in the Volunteer force, having been Lieut.-Colonel commanding, and Honorary Colonel of, the 1st Northumberland Brigade R.G.A. Volunteers (later R.F.A. Territorial); and he was responsible for the equipment of the Elswick battery which went to the Boer war. He was keenly interested in the preservation of the "Victory," and was Chairman of a Technical Committee appointed to superintend her restoration.

He married in 1875 Elise Isabelle, daughter of the Chevalier Gustave Simoneau, of Brussels. Of his two daughters, one married in 1907 Commander A. P. N. Thorowgood, D.S.O. He died of pneumonia in London, on the 15th March, 1926, and was buried in the Brompton cemetery.

Digitized by Google

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1925-1926.—PART 2.

Admission of Students, 79, 157, 211.

Aitken, T. M.—*Discussion on Electric Welding :* Welding the joints of a large marine boiler, 183 ; tests of riveted and welded joints, 184 ; annealing, 187.

Anderson, E. P.—*Correspondence on the Khyber Railway :* The original alignment, 54 ; unusual " political " conditions under which work was carried out, 54 ; relative merits of top and bottom headings in tunnels, 54 ; stresses in piers, 54 ; addition of Portland cement to lime-surkhi mixture, 55.

Anderson, J. T. N.—*Correspondence on Electric Welding :* Value of the Paper, 188 ; day-labour in Australia, 188.

Associate Members transferred to the class of Members, 79, 157, 211.

Auditors, vote of thanks to, 268 ; reappointment of, 268.

Bayley, V.—" *The Khyber Railway,*" 1.—*Appendix*, 20.—*Discussion :* Radius of curves, 53 ; question of a break of gauge, 53 ; new Indian construction gauge, 53 ; failure of the 3½-ton lorries, 53 ; average monthly mileage for steam lorries, 53.—*Correspondence :* Site of high girder bridges on steep gradients, 74 ; depth of curtain walls, 74 ; electric traction, 74 ; use of lime concrete in India, 75.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Location of the line, 143 ; question of providing crossing-stations and catch-sidings, 143 ; curvature, 143 ; method of transporting materials of construction to the summit, 143 ; depth and side slope of cuttings, 144 ; method of setting out the side slopes, 144 ; comparison of tunnels with those on the Khyber Railway, 144 ; cost of excavation, 145.

Beaumont, E. G. E.—*Discussion on the Khyber Railway :* Working conditions and costs of the road transport, 52.

Botley, C. E.—*Discussion on Electric Welding :* Welding in connection with gasholders, 182 ; question of cost, 183.

Bourne, T. J.—*Correspondence on the Khyber Railway :* " Work numbers " system of allocations of expenditure, 55 ; settlement of banks, 56 ; use of side-tip wagons, 56 ; question of building the arch-rings in lime-surkhi, 56 ; pioneer work in China, 56 ; formula for waterways of bridges, 57 ; braking stresses in piers, 57.

Digitized by Google

Bryan, B. W.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Cost of coal used in the test, 242 ; particulars of actual running-costs of triple-expansion engines, 242.
Burton, W. M.—*Correspondence on the Khyber Railway :* Use of the tacheometer, 57 ; adherence to easy curves, 58 ; reversing-stations, 58.

Caldwell, J.—*Correspondence on Electric Welding :* Saving effected by electric welding, 189; reliability of a welded joint, 189; list of electrically-welded buildings and miscellaneous structures in various countries, 190.
Clark, G. M.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Distinguishing between the efficiency of an engine and efficiency of the steam cycle of supply, 250.
Cohen, A. J.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Gradient and curves on the Northern Shan States Railway in Burma, 146 ; rail-wear on curves, 147 ; creep, 147.
Cotterell, A. P. I.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Steam pumping-plant compared with a suction gas-plant, 241 ; question of improvements possible by increased pressure and superheat, 242 ; relative economy of various methods of pumping, 242.
Council, election of, for Session 1926–27, 267.—Report for Session 1925–26, 269.
Cripps, F. S.—*Correspondence on Electric Welding :* Possibilities of, and objections to, electric welding, 191 ; cause of collapse of the Melbourne gasholder, 192 ; details of construction of the holder, 192 ; novel feature of the Fitzroy holder, 194 ; objection to tubular form of structure, 195 ; number of tank-guides, 195 ; roller-carriages, 195.

Dalby, Professor W. E.—*Discussion on Electric Welding :* Loss of elastic properties of a lap-welded joint, 187 ; annealing plates after welding, 187.
Dare, H. H.—*Correspondence on the Gezira Irrigation Scheme :* Proportion of mortar, 113 ; comparison between various dams of the cost per acre-foot of water stored, 113.

Election of Members, Associate Members, and Associates, 79, 157, 211.
Ellis, Sir William H.—Announcement of the deaths of Sir Bradford Leslie, Sir Philip Watts, and Professor W. H. Warren, 121.—*Discussion on Electric Welding :* Electric welding of large turbine-drums, 181 ; work in connection with repairs, 181 ; the repair of roofs of blast-furnace gas-heating stoves, 182.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Question of gauge, 147.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Importance of the subject, 238 ; behaviour of steel at high temperatures, 249.

Fairley, W.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Fuel costs of town-gas-driven plant, 252.
Forrest (James) Lecture, 1926.—"*Radio Communications*," Senator G. Marconi, 303.

Digitized by Google

Grierson, W. W.—*Discussion on the Khyber Railway :* Gradients, 47 ; minimum radius of curves, 48 ; question of the gauge, 48 ; merits of top and bottom headings in tunnel construction, 48 ; the Berne gauge, 49 ; stress in piers due to braking loads on a steep gradient, 49.

Hearn, Colonel Sir Gordon.—" *The Survey and Construction of the Khyber Railway,* 23.—*Appendixes,* 42.—*Correspondence :* Use of the aneroid barometer and the tacheometer, 75 ; levelling and check levelling of tacheometer stations, 76 ; question of the gradient, 76 ; degree of sharpness of curve, 76 ; "Work numbers" system, 77 ; lime-surkhi arch-rings in small culverts, 77 ; movement of girders on a gradient, 78 ; pockets of water, 78.—*Correspondence on the Mountain Section of the Northern Burnett Railway, Queensland :* Curves, 148 ; particulars of retaining-walls on the Khyber Railway, 148 ; method of plotting toes of banks, 149 ; protection of timber against attacks of white ants, 149.

Henderson, Sir Brodie H.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Costs, 142 ; type of locomotive for the steep section, 142 ; rack railways, 142 ; cost of the bridge-work, 142 ; weight of rails, 142.

Hider, G. E.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* History of the reciprocating engine, 253 ; question of heat-exchange in a uniflow engine and a well-designed counterflow engine, 253 ; design of the reciprocating engine, 254 ; Corliss valves, 254 ; method of reducing loss through incomplete expansion, 254.

Honeysett, A.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Experience with triple-expansion steam-engines, 245 ; relative economy of various methods of pumping, 246 ; method of determining the relative merits of pumping schemes, 246.

Hurst, H. E.—*Correspondence on the Gezira Irrigation Scheme :* Forecast of discharge of the sluices by means of model experiments, 114.

Husbands, H. W. S.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Question of possible future conversion to the standard gauge, 145 ; enlargement of the actual tunnel profile on sharp curves, 145 ; merits of the six-bolt fish-plates, 146.

Irrigation.—" *The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile,*" O. L. Prowde, 81.—Introduction, 81.—Sennar dam, 83 ; design, 83 ; foundations, 85 ; springs, 86 ; masonry, 86 ; cement-factory, 87 ; sluice steelwork, 88 ; possible erosion of down-stream foundation, 88.—Construction of the dam, 89 ; excavation, 91 ; progress of construction, 91 ; labour, 94.—Reservoir, 95.—Canalization, 95 ; method of excavation, 95.—*Appendixes,* 97.—*Discussion :* Sir Murdoch MacDonald, 100 ; A. G. Vaughan-Lee, 102 ; M. F.-G. Wilson, 105 ; W. L. Lowe-Brown, 106 ; J. S. Wilson, 108 ; O. L. Prowde, 110.—*Correspondence :* H. H. Dare, 113 ; H. E. Hurst, 114 ; J. M. Lacey, 115 ; W. L. Strange, 117 ; O. L. Prowde, 118.

Johnson, F. R.—*Correspondence on the Khyber Railway :* Use of the barometer, 58 ; surveying with angular levels and chained distances, 59 ; details of reconnaissance surveys in the United and Central Provinces, 59 ;

Digitized by Google

question of levelling and check levelling of tacheometer stations, 60; system of chaining combined with angular levels to height of instrument, 61.

Keable, E. F.—*Correspondence on Electric Welding:* Internal corrosion of gasholders, 196; oil-filming of gasholder water-surfaces, 196.

Kernot, Associate-Professor W. N.—*Correspondence on Electric Welding:* Tests in connection with strength of joints, 196; deformation due to heating of the plates during welding, 196; data furnished by testing a bar made of electrode metal, 197; welded roof-trusses, 197; applications to repair work without interruption of supplies, 197; corrosion, 197; effect of electrolysis, 197; training of welders, 198.

Key, T. D.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water:* Comparative working-costs of steam and Diesel pumping, 255; Diesel-driven plant, 257.

Kirkpatrick, Sir Cyril.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland:* Method of putting in batter-lines of banks and cuttings, 147.

Lacey, J. M.—*Correspondence on the Gezira Irrigation Scheme:* Question of growing crops in rotation on the irrigated area, 115; nature of the soil, 116; season and period of the cotton crop, 116; composition of mortar, 116.

Leitch, W. O.—*Correspondence on the Khyber Railway:* Depth of curtain walls, 61; effect of restricting channels, 61; details of constructing a tunnel in North China, 62.—*Correspondence on the Mountain Section of the Northern Burnett Railway, Queensland:* Question of day labour, 149; price of retaining-wall concrete, 149.

Leslie, Sir Bradford.—Announcement of the death of, 121.

Lillie, G. E.—*Correspondence on the Khyber Railway:* Stragetic railways on the Indian frontier, 62; question of the use of steam and not electric traction, 63; gradients, 63; special points for the Simla goods station, 64; gauge of the line, 65; use of the aneroid barometer and the tacheometer for preliminary survey work, 66; difficult nature of the construction work, 66; arch culverts skew to the railway centre-line, 67.—*Correspondence on the Mountain Section of the Northern Burnett Railway, Queensland:* Location of the line, 149; method of taking cross sections, 150; masonry for construction of retaining-walls, etc., 151; use of concrete shoots for carrying water across the railway, 151; relaying the line on the Kalka Simla Railway, 151; bending rails before putting them into the road, 152,

Lowe-Brown, W. L.—*Discussion on the Gezira Irrigation Scheme:* Foundations, 106; differences between the Assuan dam and the Sennar dam, 106; unknown factors in connection with the Assuan dam, 107; comparisons between the two dams, 107; composition of mortar, 108.—*Discussion on the Khyber Railway:* Radius of curves, 50; use of reversing-stations, 51; tunnels in the Argentine, 51; lightness of the track, 51; transition-curves, 51.

Lubbock, Brigadier-General Guy.—*Discussion on the Khyber Railway:* Labour difficulties, 50.

Digitized by Google

Lupton, H. R.—"*The Triple-Expansion Steam-Engine as applied to the Pumping of Water, with special reference to the Plant at Lea Bridge,*" 212.—*Appendixes*, 229.—*Discussion :* Future tests, 238 ; accuracy of figures, 238.—*Correspondence :* Running-costs for electric power, 260 ; boiler efficiencies, 261 ; price of coal, 261 ; electric drive competing with various forms of steam drive, 261 ; Lea Bridge pumps compared with electrically-driven set, 261 ; initial cost of foundations and buildings, 262 ; town-gas-driven plant, 262 ; relative costs of steam and Diesel pumping, 263 ; flexibility of the Diesel engine, 263 ; duration of life of high-speed machinery, 263 ; Corliss valves, 263 ; more efficient utilization of the exhaust end of the heat-drop, 264 ; driving of the boiler feed-pump, 265 ; division of efficiency into three factors, 265 ; question of improving the efficiency of the engine by making steam conditions worse, 265.

MacDonald, Sir Murdoch.—*Discussion on the Gezira Irrigation Scheme :* History and functions of the Sennar dam, 100 ; cotton-growing on the Gezira plain, 100.

Marconi, Senator G.—"*Radio Communications*" (James Forrest Lecture, 1926), 303.—Acknowledgment of vote of thanks, 320.

Maude, A.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Substitution of a turbine, driving a centifugal pump, for the low-pressure cylinder, 258.

Mawson, J. H.—*Correspondence on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Comments on the trial figures, 259.

Meeting, Annual General, 267.

Moore, M.—*Correspondence on Electric Welding :* Application to the fabrication of structural steel, 198 ; the Cutler-Marsden machine, 198 ; covered electrodes, 198 ; training of welders, 199 ; joints and designs should be laid out to suit electric welding, 199 ; desirability of additional data being furnished, 200.

Nolan, T. R.—*Correspondence on the Khyber Railway :* Braking-stresses in bridge-piers and girders, 67.

Original Communications received 1925–26, 300.

Palmer, F.—*James Forrest Lecture*, 1926.—Remarks in proposing a vote of thanks to the lecturer, 320.

Plumstead, A. E.—*Discussion on Electric Welding :* Possibilities of welding, 185; cost, 185; cause of internal corrosion of the crown of the gasholder, 185 ; allowance for contraction effects in the weld, 185 ; repairing a gasholder at Norwich, 186 ; radial bar system of strengthening the crown, 186 ; strength of thin plates on each side of a welded joint, 186.

Prowde, O. L.—"*The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile,*" 81.—*Appendixes*, 97.—*Discussion :* Leakage through the masonry, 110 ; no provision for artificial cracking places, 111 ; erosive action of the water downstream of the dam, 111 ; silt-level and height of the sills, 111 ; use of steel sheet piles, 112 ; question of masonry-

Digitized by Google

pressure exceeding the hydrostatic pressure, 113.—*Correspondence :* Size of the granite hearting, 118 ; comparison of cost between the Sennar dam and the Assuan dam, 118 ; division of cost of work and proceeds of sale of cotton crops between the Sudan Government and the Sudan Plantations Syndicate, 118 ; nature of the soil, 119 ; season and period of the cotton crop, 119 ; composition of the mortar, 120 ; discharge measurements, 120 ; rate of execution of the work, 120.

Pumping.—See Steam-Engines.

Railways.—" *The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland,*" A. E. Tuffley, 121.—The Northern Burnett Settlement Scheme, 123 ; location, 124 ; transport, 125 ; conditions and rates of pay, 127 ; earthworks, 127 ; method of setting out batter-lines, 129 ; the field procedure, 130 ; retaining-walls, 132 ; tunnels, 133 ; waterways, 135 ; bridges, 135 ; permanent way, 137 ; locomotives, 138.—*Appendix,* 139.—*Discussion :* Sir Brodie H. Henderson, 142 ; V. Bayley, 143 ; H. W. S. Husbands, 145 ; W. A. Willox, 146 ; A. J. Cohen, 146 ; Sir Cyril Kirkpatrick, 147 ; Sir William H. Ellis, President, 147.—*Correspondence :* Colonel Sir Gordon Hearn, 148 ; W. O. Leitch, 149 ; G. E. Lillie, 149 ; A. W. Rendell, 154 ; A. E. Tuffley, 154.

—— " *The Khyber Railway,*" V. Bayley, 1.—Location, 2 ; Jamrud to Shahgai, 2 ; Shahgai to Kata Kushta, 3 ; Kata Kushta to Landi Kotal, 3 ; Landi Kotal to Landi Khana, 3.—The Tribes, 4 ; tribal labour and contractors, 5 ; security, 6 ; housing, sanitation and welfare, 8.—Plan of operations, 8 ; materials, 9 ; water, 9 ; building stone, 9 ; lime, 9 ; bricks, 9 ; concrete, 10 ; mortar, 10.—Construction. 10 ; earthwork, 10 ; tunnels, 11 ; special difficulties in tunnels, 13 ; bridges, 16 ; retaining-walls, 17 ; permanent way, 17 ; stations, 18 ; motor transport, 18.—Personnel, 19.—*Appendix,* 20.

—— " *The Survey and Construction of the Khyber Railway,*" Colonel Sir Gordon Hearn, 23.—Topography, 24.—Geology, 26.—Khyber route, 27.—Reconnaissance survey, 28 ; Bagiari to Shahgai, 29 ; the Ali Masjid gorge, 30 ; Landi Kotal to Landi Khana, 31.—Curvature, 32.—Preliminary survey, 32.—Location, 33.—Work numbers, 33.—Designs of works, 34.—Execution of work, 39.—Organization and cost, 40.—*Appendix,* 42.

—— *Discussion on the two foregoing Papers :* W. W. Grierson, 47 ; Brigadier-General Guy Lubbock, 50 ; W. L. Lowe-Brown, 50 ; E. G. E. Beaumont, 52 ; V. Bayley, 53.—*Correspondence on ditto :* E. P. Anderson, 54 ; T. J. Bourne, 55 ; W. M. Burton, 57 ; F. R. Johnson, 58 ; W. O. Leitch, 61 ; G. E. Lillie, 62 ; T. R. Nolan, 67 ; B. Ripley, 68 ; F. G. Royal-Dawson, 69 : R. Stirling, 71 ; H. Stringer, 72 ; V. Bayley, 74 ; Sir Gordon Hearn, 75.

Reeson, J. N.—" *The Influence of Electric Welding in the Design and Fabrication of Plant and Structures,*" 158.—*Appendixes,* 179.—*Correspondence :* Strength of the weld, 203 ; cost of covered electrodes, 204 ; question of cost, 204 ; time taken to reconstruct the North Melbourne gasholder, 206 ; stresses due to temperature-changes, 207 ; details of construction of the gasholders, 207 ; the Cutler-Marsden

Digitized by Google

welding machine, 209; question of corrosion of either the welding metal or metal adjacent to the weld, 209; brazing cast-iron pipes, 210.

Rendell, A. W.—*Correspondence on the Mountain Section of the Northern Burnett Railway, Queensland:* Profile of line and other particulars concerning certain train trials in France, 154.

Ripley, B.—*Correspondence on the Khyber Railway:* Gradients, curves and reversing-stations on the Canadian Pacific Railway, 68.

Ritchie, E. G.—*Correspondence on Electric Welding:* Particulars of resistance to corrosion of electrically-welded joints, 200; details of welded steel pipes in the Melbourne water-supply system, 201.

Royal-Dawson, F. G.—*Correspondence on the Khyber Railway:* Question of the gauge and curves, 69; Mallet and Garratt engines, 70; bridges designed to standard loading recommended by the late Indian Bridge Committee, 71.

Scrutineers of the ballot for the election of Council, appointment of, 211; vote of thanks to, 268.

Smith, R. T.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water:* The first pumping-engine at Lea Bridge, 238; question of increasing the working range of the steam, 239; economy of the triple-expansion reciprocating pumping-engine, 239; comparison of costs between the electrically-driven pump and the steam-driven pump, 240.

Steam-Engines.—"*The Triple-Expansion Steam-Engine as applied to the Pumping of Water, with special reference to the Plant at Lea Bridge,* 212.—The Lea Bridge plant, 212.—Test, 214.—Analysis of test, 217.—Improvements and developments, 222.—Comparison with other types of pumping machinery, 224; oil-driven reciprocating pumps, 225; steam-turbine-driven centrifugal pumps, 226; electrically-driven pumps both centrifugal and reciprocating, 227.—*Appendixes,* 229.—*Discussion:* Sir William H. Ellis, President, 238, 249; H. R. Lupton, 238; R. T. Smith, 238; A. P. I. Cotterell, 241; B. W. Bryan, 242; H. E. Stilgoe, 243; A. Honeysett, 245; R. A. S. Thwaites, 248.—*Correspondence:* G. M. Clark, 250; W. Fairley, 252; G. E. Hider, 253; T. D. Key, 255; A. Maude, 257; J. H. Mawson, 259; J. N. Reeson, 260.

Stilgoe, H. E.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water:* Details of the operation of the Metropolitan Water Board's steam pumping-engines, 243.

Stirling, R.—*Correspondence on the Khyber Railway:* Saving due to adoption of sharper curves on the Tocopilla mountain railway, 71; Meyer-Fairlie locomotives, 71; lubrication of tire-flanges, 72.

Strange, W. L.—*Correspondence on the Gezira Irrigation Scheme:* Foundations, 117; opposition of Egypt to the scheme, 117; benefit to Egypt of proposed schemes at Gebel Aulia and at Lake Tsana, 118; effect of monsoon irrigation on downstream flow in the Punjab, 118.

Stringer, H.—*Correspondence on the Khyber Railway:* Talbot formula for waterways of culverts, 72; concrete used in China, 73; hand-drilling on the Pekin-Mukden Railway, 73.

Telegraphy.—"*Radio Communications,*" Senator G. Marconi (James Forrest Lecture, 1926), 303.

Digitized by Google

Thwaites, R. A. S.—*Discussion on the Triple-Expansion Steam-Engine as applied to the Pumping of Water :* Cost of Lea Bridge plant compared with electrically-operated plant, 248 ; question of boiler efficiency, 248 ; price of coal, 248 ; electricity as a rival to the steam pumping-engine, 249.

Transfer of Associate Members to the class of Members, 79, 157, 211.

Tuffley, A. E.—" *The Construction of the Mountain Section of the Many Peaks to Northern Burnett Railway, Queensland,*" 121.—*Appendix,* 139.—*Correspondence :* Survey, 154 ; transition-curves, 154 ; gauge, 154 ; headings used in taking out cuttings, 154 ; construction of the tunnels, 155 ; employment of day-labour, 155 ; protection against ants, 155 ; cost of steelwork, 155 ; sleepers, 155 ; weight of rails, 156 ; use of six-hole fish-plates, 156.

Vaughan-Lee, A. G.—*Discussion on the Gezira Irrigation Scheme :* Rain-grown cotton in the Sudan, 102 ; Egypt not deprived of water by the Sennar dam, 102 ; possible dams at Lake Tsana and Lake Albert, 103 ; seepage on the east and west banks of the dam, 104 ; necessity for aprons on the downstream side, 104 ; question of the design, 104 ; canalization, 105.

Warren, Professor W. H.—Announcement of the death of, 121.

Watts, Sir Philip. Announcement of the death of, 121 ; memoir of, 321.

Welding.—" *The Influence of Electric Welding in the Design and Fabrication of Plant and Structures,*" J. N. Reeson, 158.—Gasholder construction, 161 ; Fitzroy 2½-million-cubic-foot holder, 168 ; re-construction, 168.—Various applications, 175.—*Appendixes,* 179.—*Discussion :* Sir William H. Ellis, President, 181 ; C. E. Botley, 182 ; T. M. Aitken, 183, 187 ; A. E. Plumstead, 184 ; Professor W. E. Dalby, 187 .—*Correspondence :* J. T. N. Anderson, 188 ; J. Caldwell, 189 ; F. S. Cripps, 191 ; E. F. Keable, 196 ; Associate-Professor W. N. Kernot, 196 ; M. Moore, 198 ; E. G. Ritchie, 200 ; J. N. Reeson, 203.

Willox, W. A.—*Discussion on the Mountain Section of the Northern Burnett Railway, Queensland :* Steepness of the gradient, 146 ; method of transporting materials of construction to the summit, 146 ; type of locomotive, 146.

Wilson, J. S.—*Discussion on the Gezira Irrigation Scheme :* Comparison between the section of the Sennar dam and that of the original Assuan dam, 109 ; stresses on upstream face of the dam, 109 ; level of the silt, 109 ; percolation of water through masonry, 110 ; provision of artificial cracking places for temperature effect, 110.

Wilson, M. F.-G.—*Discussion on the Gezira Irrigation Scheme :* Red cement, 106 ; Portland blast-furnace cement, 106 ; discharge of the river and the abstraction of water, 106.

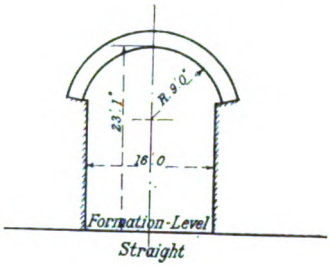
Digitized by Google

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
DUKE STREET, STAMFORD STREET, S.E., AND GREAT WINDMILL STREET, W.

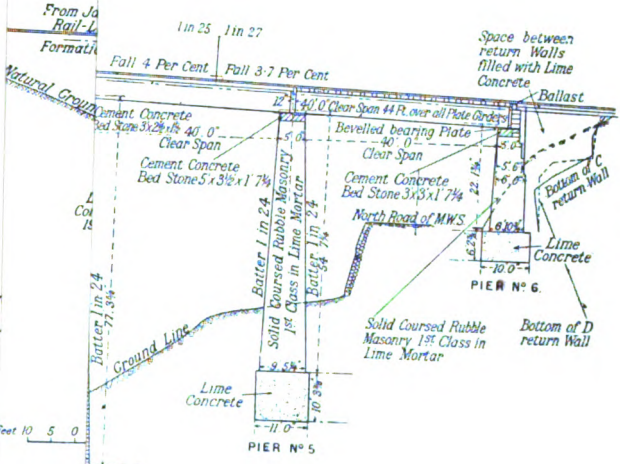
Digitized by Google

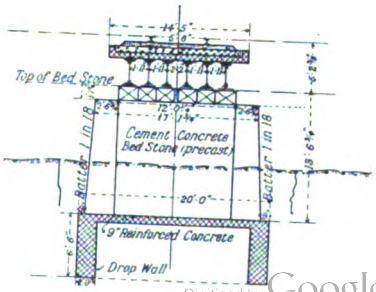
PLATE 1.

THE KHYBER RAILWAY.



SECTION D.


1 in 25
1 in 27
Fall 4 Per Cent
Fall 3·7 Per Cent
Space between return Walls filled with Lime Concrete
Ballast
40'0 Clear Span 44 Ft. over all Plate Girders
Bevelled bearing Plate
40'0" Clear Span
Cement Concrete Bed Stone 5'x3½'x1'7½"
Cement Concrete Bed Stone 3'x3'x1'7½"
Batter 1 in 24
Solid Coursed Rubble Masonry 1st Class in Lime Mortar
North Road of MWS
Bottom of C return Wall
Lime Concrete
PIER No 6.
Ground Line
Solid Coursed Rubble Masonry 1st Class in Lime Mortar
Bottom of D return Wall
PIER No 5



Digitized by Google

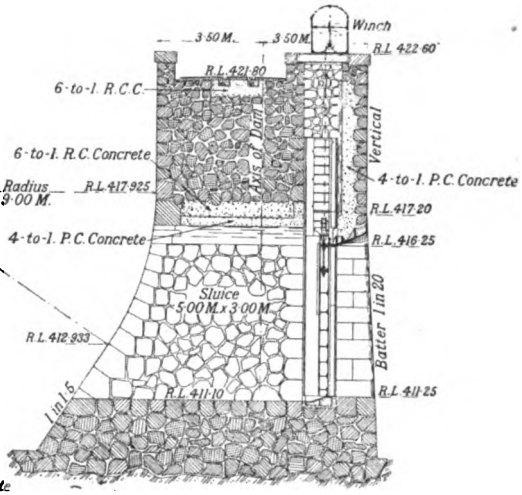
V. BAYLEY.

UNIV. OF MICH.

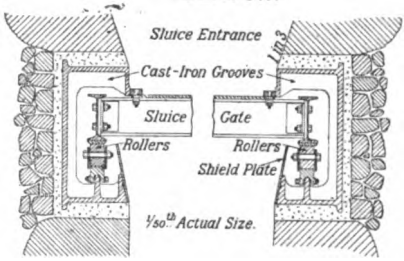
Digitized by Google

PLATE 2.

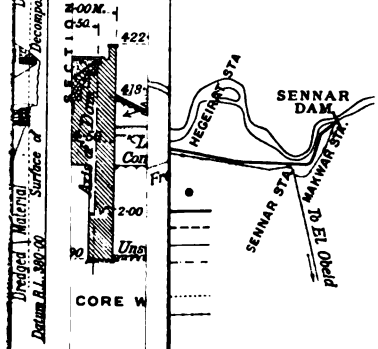
GEZIRA IRRIGATION SCHEME.



REGULATOR.



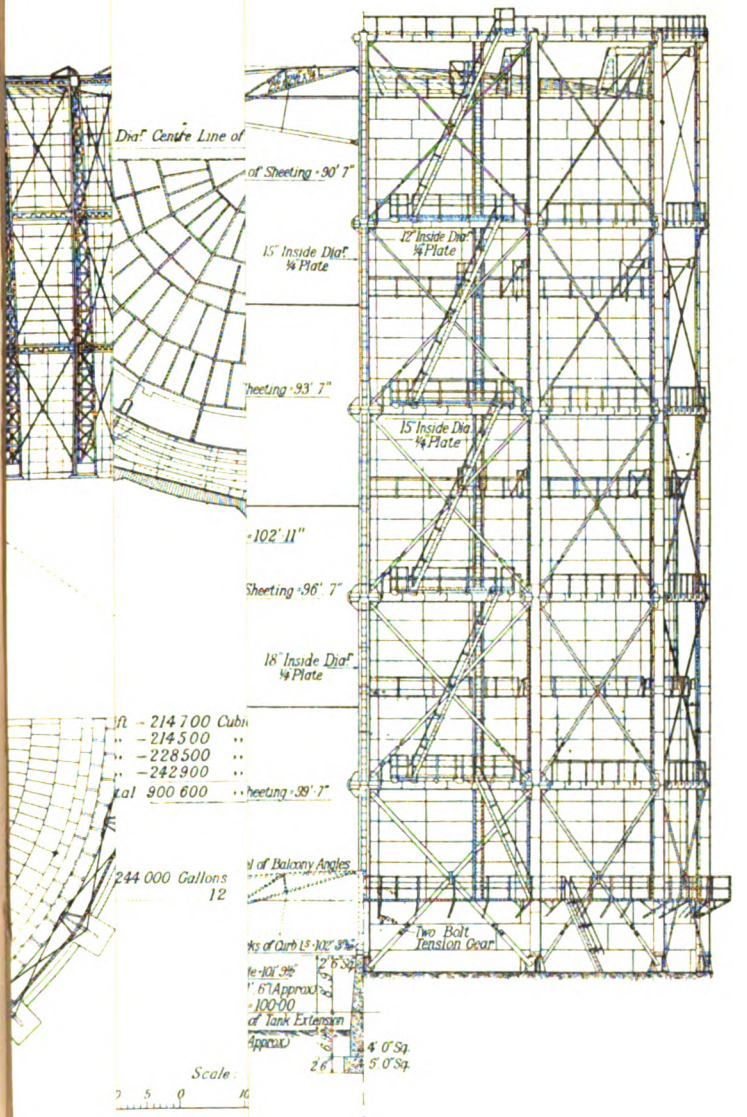
SECTION SHOWING SLUICE STEELWORK.



Digitized by Google

Digitized by Google

PLATE 3.
ELECTRIC WELDING.



TION

HALF ELEVATION

EXTENSION

R

J. N. REESON.

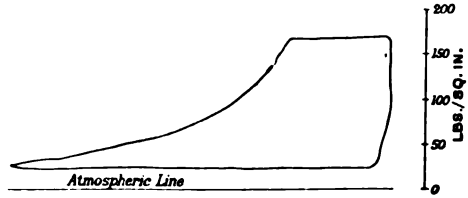
Digitized by Google

UNIV. OF MICH.

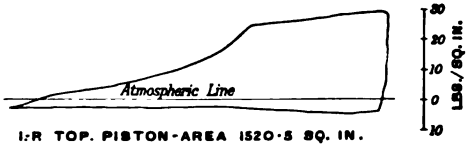
Digitized by Google

PLATE 4.
TRIPLE-EXPANSION
PUMPING-ENGINE.

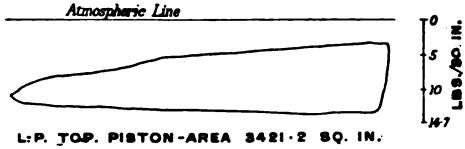
Figs. 8.



H.P. TOP. PISTON-AREA 452·39 SQ. IN.



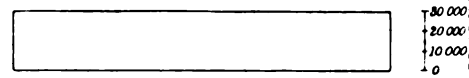
I.P. TOP. PISTON-AREA 1520·5 SQ. IN.



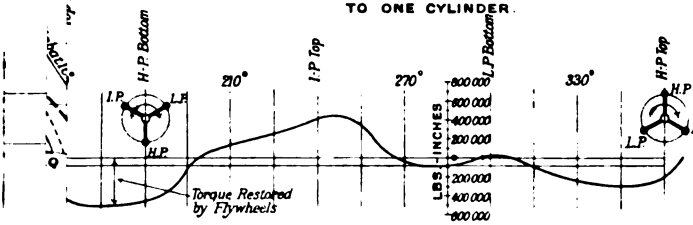
L.P. TOP. PISTON-AREA 3421·2 SQ. IN.

NDICATOR DIAGRAMS.

7IEE PUMP INDICATOR DIAGRAMS.

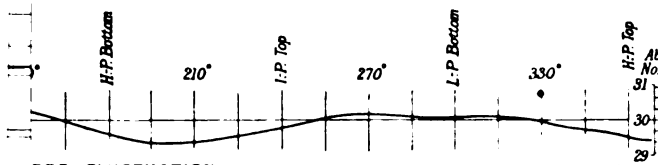


DEAD WEIGHT OF MOVING PARTS CORRESPONDING TO ONE CYLINDER.



CRANK-EFFORT DIAGRAM.

educed to the Scale of 1 Square Inch =200,000 Foot-Lbs of Work



EED-FLUCTUATION.

Digitized by Google

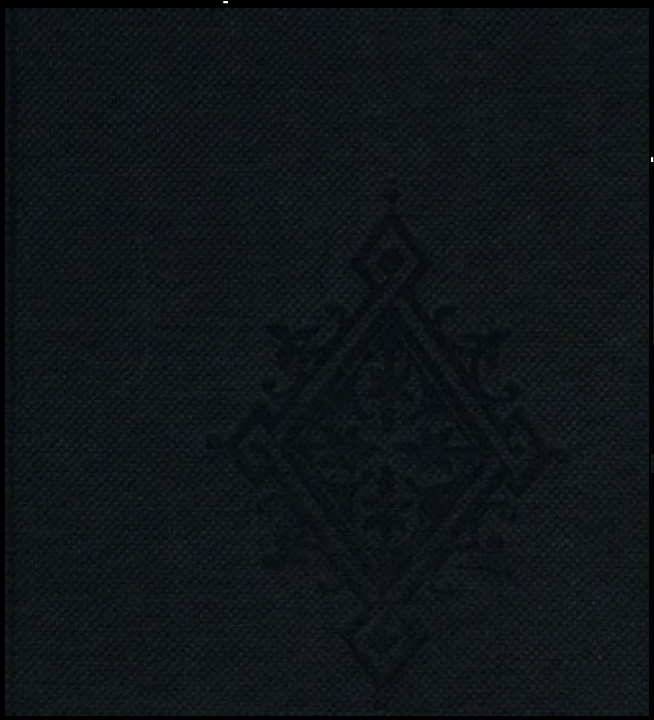
Digitized by Google

Digitized by Google

Digitized by Google

UNIVERSITY OF MICHIGAN
3 9015 06360 2406

Digitized by Google



Digitized by Google